DANGER EXPOSED PROPELLER BLADES

Designing an Intelligent Propeller Safety System

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Contents

1 Introduction

My interests lie within the area of water sports. I have a passion for fast motor boats and everything that comes along with it (engines, boat equipment) and sports like water-skiing and wake boarding. I perform these myself and have great pleasure doing this. I often question myself about possible improvements to boats and boat equipment. There are all kinds of little issues on a boat that could easily be solved by using simple technologies.

Thinking of possible topics for my individual project I wondered why such little attention is paid to safety on boats in comparison to cars. Of course cars and boats cannot be fairly compared on this topic because cars are our every day transportation and it is necessary to make them as safe as possible to save the lives of many people. Though I think that there can be paid some more attention to boats, respecting the very dangerous way of propulsion. As a normal three bladed propeller running at 3600 rpm strikes an object in its path 180 times a second, boats are equipped with a murder weapon.

Every year accidents happen with boats and water sports, days that should be fun and pleasurable can turn into nightmares. Accidents with people performing water sports like wakeboarding and water-skiing, but also with average families just having fun on the water. With the increasing number of pleasure crafts and the increasing occupation of the available water sport recourses (lakes, rivers) accidents are bound to happen. Existing, commonly used safety systems like lanyard death man's switches and additional systems like propeller guards help preventing accidents with boat propellers but not sufficiently (in my opinion).

I am convinced of the fact that "simple" warning or emergency systems could improve safety of boat propellers and can prevent accidents from happening. Yet, some propeller guard systems are available but they are not widely known and have many problems. In this project I like to tackle this safety issue and design a user friendly and easy to install system that provides the safety-caring boat owner or family with a choice to protect them against these horrible accidents and make their pleasurable days on the water even more pleasurable and carefree.

Objective 2

2.1 Areas of investigation and results

In my project I will focus on designing a propeller safety system for fast motor boats equipped with an outboard engine or a stern drive in the recreational sector. This system should prevent both passengers on the boat as swimmer and other holiday-makers from getting injured by a boat's propeller.
From my brief investigation I found out that most accidents happen with people: being in the water at the rear of a boat when the boat starts in forward direction or is backed up towards a swimmer or skier, the propeller is left running and people falling overboard. Another cause is boats running over a person in the water. [2]

2.1.1 Existing solutions

I found out that there is a good solution available for injuries caused by falls overboard [Virtual Lifeline, 5] and for the skipper these kinds of solutions are even compulsory to wear. For the other problems there are only partial or performance limiting solutions available. Yet there are a number of electronic solutions patented not influencing a boats handling and performance. Special shaped propellers like the RingProp [RingProp PLC, 4] do prevent from blade cuts, since there are no open blades but can still cause severe injuries. Advantages are that they do not influence a boats performance. Propeller guards based on fully or partial covering the propeller like the SwimGuard Pro [MariTech Industries, 5] are only suitable for boats below planning speed (approximately 30 km/h) because they influence the boat's performance, handling and fuel consumption.
The best protection now available, considering the fact that this guard improves the boats efficiency and handling, is the PropGuard. [W. C. Schultz Engineering INC, 7]. This guard partially covers the propeller, protecting against side and front entries, but lacks protection against rear intrusion. This causes the raised risk of limb entrapment causing more severe injuries.
A switch shutting down the engine when the swim ladder is lowered like the Prop Stopper [MariTech Industries, 5] is a good solution for the prevention of accidents with swimmers or skiers that use the swim ladder. When the swim ladder is not used this system obviously does not work. Though it is a piece of extra safety and will also help the boater remember that the ladder is down (in my experience this is forgotten quite often).

For more extended and detailed information about existing solutions see: Appendix 8.4 Existing solutions.

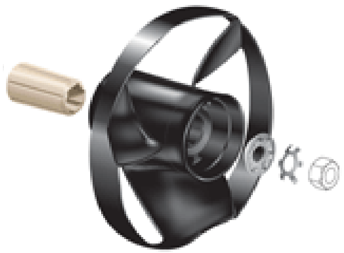


Fig. 2.1.1.1 RingProp

Fig. 2.1.1.2 SwimGuard Pro

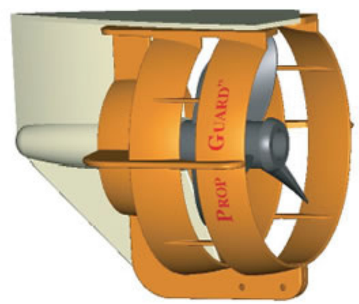


Fig. 2.1.1.3 Propguard

2.1.2 Accident counts

During orienting research I found out that propeller strikes are a big problem in the USA. In 2003 there occurred 703 fatalities and 3.888 injuries that needed medical treatment on a total of 5.438 accidents. In this year 12.794.616 motorboats where registered in the USA, which comes to a fatality rate of 5,5 for 100.000 motor boats [US Coastguard]. This causes an active search for solutions for this problem. In the Netherlands accidents are less common; before the end of June 2000, 14 accidents are registered, in 1999 3 fatal accidents occurred [9]. Research in newspaper archives came up with an average of 1 or 2 accidents a year on 140.000 registered motor boats in the Netherlands (1999) [HISWA]. Most recent accidents: 4 Aug. 2004 a man dies after jump of his speedboat with the propeller left in reverse. 13 July 2003: 11 year old girl looses a leg and a 47 year old man is severely injured after they fall of their boat as a result of big waves. At the same time the skipper started the propeller which stroke both the girl and man.
The difference in accident rates between the USA and the Netherlands might relate to education. In the Netherlands a boat licence is obligated and boaters are aware of the danger related to running propellers. In the US a licence is not obligated (depends from state to state) and in a state like Rhode Island where a licence is obligated accident counts are zero. Although education seems to be a solution to the problem, accidents keep happening due to little moments of inattention or recklessness and carelessness due to frequent operation.

Most common causes:

Causes US research [2]

- They are in the water at the rear of the boat as a result of swimming or skiing and the propeller is started in a forward direction.
- They are in the water at the rear of the boat as a result of swimming or skiing and the boat/propeller is backed into them, such as when backing up to a skier.
- They fall out of a moving boat and are struck by the boat as it passes over them, they tend to fall over the side during a sharp turn or from the front of a bow rider or a pontoon boat.
- They fall out of a moving boat and it circles around (without a skipper) and runs over them, sometimes repeatedly.
- They are in the water swimming, diving or adjusting their water skis, not seen by a boater, and are ran over and struck by the propeller.
- They are in a collision. One boat or PWC is typically broadsided by another boat that actually runs over it with the propeller striking one or more people in/on the first boat/PWC, or an occupant of a boat being knocked under its own propeller during a collision.
- On rare occasions people on land (the shore), a pier or a floating dock/marina are stuck by a propeller when a boat actually runs over them.

For accident scenarios see: 2.3.2 Scenarios

Project Goal 2.2

For my project I think the challenge lies in designing a propeller guard system with the use of sensors that can detect persons in the area of the running propeller and alarm the skipper or intervene (shut down the engine/shift to neutral). I will focus on protecting people already in the water or entering the water at the rear of the boat as well people underneath and alongside the boat, approaching the propeller dangerously. This system should at least protect persons at low speed like in most occasions during swimming from a boat, water-skiing and performing other water related sports. At high speeds the tail-piece of the outboard/stern drive and the lower part boat can already cause severe injury. Besides designing the electronic system my focus will also be on the shape the system comes in and the required installation on the boat. I think that this can be a decisive issue as it comes for customers to buy such a system. I will to focus on safety concerning boaters which like to have a carefree use of their boat. My design should be an additional safety system which reduces the risk of propeller strikes and I should take care of not designing pseudo-safety causing users to get reckless, it should be an addition to their own care and responsible behaviour.
As a result I will deliver a working (simulation) of the technological solution and a physical prototype showing the direction of the product, including the installation on the boat.

Fig. 2.2.1 Mercury outboard

2.3 Design decisions and assumptions

The design problem I am dealing with is a very complex one. In the first place, because propeller related accidents are often caused by an unfortunate concurrence of circumstances, a second is that accidents happen due to a wide variety of causes. Another issue that makes it complex are the very complex conditions the system has to perform under e.g. high speeds, different water conditions, different environmental circumstances etc.

2.3.1 Setting boundaries

On of the first decisions I made was to exclude the protection of swimmer/water-skiers which are ran over by boats at high speeds. Reasons for this decision:

- According to US research this situation is not the most dangerous and biggest problem
- Driver should take care of not hitting other boats and swimmers
- Consumers are more willing to pay money for their own safety than the safety of others
- According to the causes I found during research, most accidents happen with the boat the victim was riding on.
- At high speeds hitting the hull and the tailpiece of the drive can already cause fatalities*.
- At high speeds the system should look ahead very far and react very quick which is difficult to realise seen the conditions (protecting swimmer in the path of a speeding boat is a specific issue which requires specific measurements)

Fig. 2.2.2 Mercruiser stern drive

What situations should (at least) be covered by the product?

- Dangerous situations with persons already in the water close to a running propeller
- Intentionally and unintentionally (falling overboard) entering the water

* "Water is much denser than air. A person struck by an object in water suffers a much greater impact than being struck by the same object at the same speed in air. One U.S. Coast Guard report says being struck by an object in water at 1 mile per hour (1,6 km/h) is equivalent to being struck by the same object in air at 29 miles per hour (47 km/h)." [2] This is also an important argument against cages around the propeller which increase the cross sectional area of impact.

2.3.2 Scenarios

Although this decision narrows down the area in which the product should work, it is still too versatile and broad to work towards a solution. To get more grip on the complex situation and to get a better focus of the problem to be solved (and the target group addressed), I made scenario's covering the most common dangerous situations. These scenarios are common occupations on the water which can lead to dangerous situations.

These scenarios should provide me with a starting point allowing me to tackle a specific situation and expand the solution to make it work for more situations in the scenario (or in the others). The assumption is that if the system works in these situations it will also work for other thinkable awkward situations.

The three scenarios are:

1. travelling at high speed --> increased risk of falling overboard
2. swimming from a boat --> commonly done, increased risk
3. waterskiing (or similar) --> increased risk of injury because the motor could not always be shut down

The scenarios are based on own experience, observation and research.

Red cross indicates area of impact

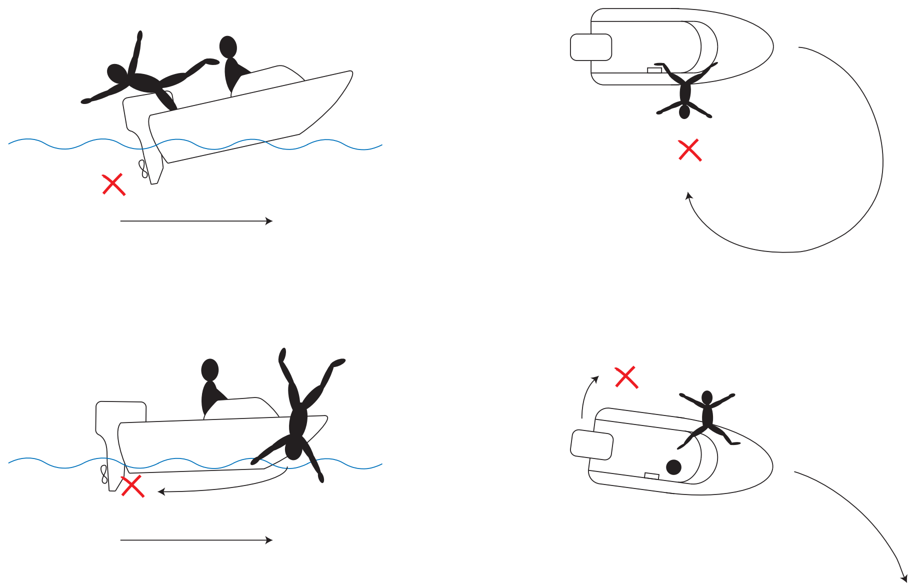
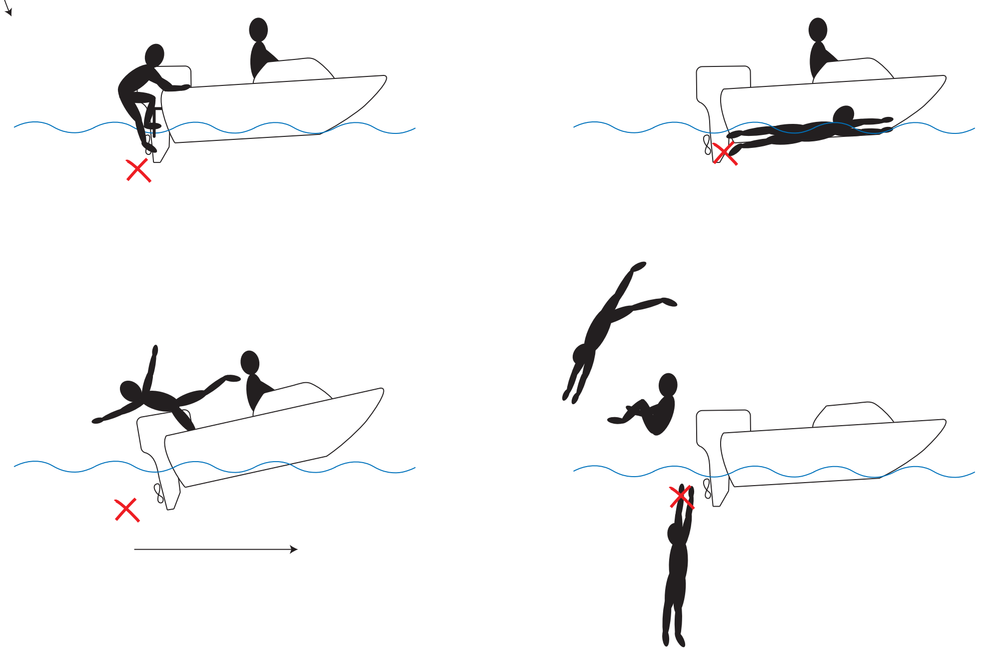


Fig. 2.3.2.1 Scenario One: travelling at high speed

Fig. 2.3.2.2 Scenario two: Swimming around the boat



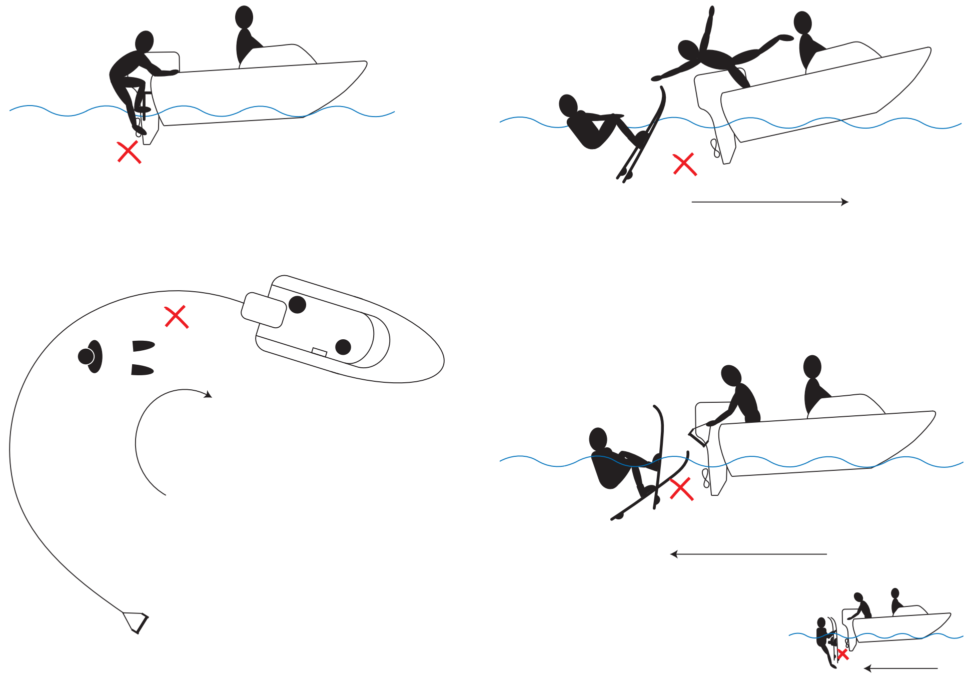


Fig. 2.3.2.3 Scenario three: Water-skiing

I decided to go for the water-skiing scenario because:

- a solution for the specific falling overboard does already exist (VirtualLifline)
- increased risk during water-skiing in contrast with swimming, motor should "standard" be shut down during swimming for forgetting there is already a solution (swim ladder interlock)

Users 3

3.1 Target Group

“Users of the existing propellers guards (in the Netherlands) are general motorboat owners which are willing to spend money on boating safety and professionals (fire brigades, divers, police etc.)”
[Bouwmeester Watersport BV, Dutch importer of the PropGuard]

The intended users of my design are owners of fast motorboats equipped with an inboard engine with stern drive or outboards, in the recreational sector. These users could be people who perform water sports like water-skiing and wakeboarding at an amateur level and people with children playing and swimming in the water near their boat. These people have an increased risk of propeller related injuries because they are often in the water near their boats.
The reason that I focus on stern drives and outboard engines is that the propulsion units of these types are located directly behind the boat instead of underneath the boat. This causes increased risks of propeller strikes when people are in the water at the rear of the boat which is unavoidable during water-skiing and wakeboarding. Professional water-skiers use special water-ski boats whereby the propeller is located underneath the boat (towards the middle) reducing the risk of propeller strikes.

According to the online questionnaire I performed the target group mentioned above corresponds with the type of users say to be interested in a safety system and is similar to numbers of accidents in the US [3]. The same goes for the type of propulsion (which obviously also depends on the type of boat)

3.2 Project Focus With Respect to the User

3.2.1 Questionnaire

Because my family and I are boaters and water-skiers ourselves and because I know quite some people who perform these activities too, I have quite an idea of what happens on the water and what possible problems regarding safety are.
Though, I have to investigate how accidents occur and what people do to prevent these accidents.
I personally feel the need for these safety systems because with the current state of technology we should be able to deal with this safety issue and find a good solution. To check whether other boaters feel the same, I like to perform a small inquiry. This inquiry should also address issues like demands and wishes of the user and how they deal with the safety issue currently. The results of these questions could help me to set up a list of demands and wishes and will be taken into account during the design process.
Another approach to find out the need for such a system is to check sales rates of existing applications in a small market research. I like to perform a small market investigation to get an idea of the Dutch market size.

For my questionnaire I will need a large amount of participants. I will ask acquaintances and could post a questionnaire on internet forums about water sports.

3.2.2 User test

My initial idea was to build a working prototype and perform a user test with it. During the scope of the project I realised that building a working prototype which would be ready to perform a user test with would be very difficult to realise. During such a user test there should naturally be taken special safety precautions to prevent real accidents from happening. The working prototype changed to a simulation. So the user test should also be a simulation. A wizard-of-oz study seemed to be a good solution. I could pretend to be the system, checking if there is somebody in the water in range of the propeller and if someone got in the area of the propeller I could sound an alarm and if that somebody got dangerously close I could pull off the ignition cut-off cord. But even this could be too dangerous to do with a running propeller, so the boat should be put into neutral before getting close to a person. In this way I questioned my self if it would be realistic enough to call it a user test. Another issue is that it is a safety system and it would be best to test it in realistic situation to investigate how users will respond to the system. Also, it is more important that the system will work in emergency situations than how it works.
To test if the system would work I will perform a performance test with the working simulation and will test if the system specifications will increase safety. The results of this test will be presented at my final presentation.

User Research Approaches and Findings 3.3

3.3.1 Size indication of the Dutch market

According to the Dutch importer of the PropGuard, only one of the systems available on the Dutch market, there are sold about 200 pieces a year, this is approx. 4 times a week. The PropGuard costs about 200 EUR depending on propeller size. Costs for a typical 13" propeller are 192 EUR. The main reason for buying a PropGuard is straight safety. Not performance improvement. Typical buyers of the PropGuard are general motorboat owners which are willing to spend money on boating safety. And professionals (fire brigades, divers, police etc.)

3.3.2 Research Approach

For my inquiry I set up a questionnaire. A questionnaire can provide me with relevant information which can be easy to process. I distributed my questionnaire using water sport forums on the internet. This is a time efficient way since there are tools which allow you to make an online questionnaire very quick and stores the results automatically. The results can also be processed very rapidly since they come in MS Excel format. During the time the questionnaire is online I can continue my project and it saves me one or more days finding participants and asking them to fill in a questionnaire. Disadvantages are that there is no personal contact so I can not interview them myself and ask for more explanation. I also cannot see if they are seriously filling in the form. Another possible problem is that I do not have control about the number of participants; it is just sit (fingers crossed) and hope there are enough people willing to fill in the form.
As a backup plan with too less responses I can still try to search for participants myself.

3.3.3 Brief Overview of the Questionnaire

The questionnaire is set up to answer the following questions I have:

- Are boaters interested in a system that prevents from propeller injuries
- What demands do they have towards such a system
- Are they aware of the danger of an exposed propeller and how do they deal with it
- What do they think of existing applications if they even are aware of the existence of these systems

A brief setup of the questionnaire:

A general part in which I ask they are, gender, type of boat they own and how/for what purposes they use it.

A part addressing their awareness of the danger of an exposed propeller, how they deal with it and if they are interested in a system that could provide additional safety.

A part addressing their knowledge of existing products and what they think of them.

A final part in which I ask them if they are more prepared to either have sensors on their boat or wear sensors with them and if they are interested/prepared to have more involvement in my project.

For the full questionnaire see: Appendix 8.2 Questionnaire

3.3.4 Results and Conclusions

I have processed the 27 respondents; below you can find an overview of the results and the conclusions.

Most of the participants are aware of the danger of exposed propeller blades (23 out of 27).

A majority of 17 out of 27 is interested in a system which increases the propeller's safety. The most common reason against, is that they think it is unnecessary or superfluous because they think accidents don't occur when behaving normally with proper care. Others say that there is no danger or they do not believe that it is possible to increase safety.

About half (15 out of 27) of the participants undertakes precautions to reduce the risk of propeller injuries during boating, swimming and water-skiing. Precautions include using the lanyard ignition cut of switch, putting the gear in neutral (or shutting down engine) when they enter the water or someone is near the propeller and handle with great care while the propeller is running.

A majority of 18 doesn't know that there are systems available that increase safety. Participants that know the existence of these systems claim they are superfluous or don't work sufficiently. One participant has a system installed

The participants wish the system to have the following properties.

	Number of participants
Not too expensive	6
Reliable and safe	6
Easy and quick installation (by themselves)	3
No permanent changes to the boat	3
Simple/easy of use	2
Not decrease performance and handling conditions	1
Not ugly or ungainly	1
Universal (exchangeable between multiple boats)	1

The wishes of the users are used as a starting point to set up a list of requirements: see 3.3.5 List of requirements

Regarding the target group I can say the following:

More people below the age of 50 are interested:
Age 20 – 35: 70%, age 35 – 50: 67% against 50% of 50 and older

Most people who are interested in the system, own a fast (open) motorboat below 7 meter: 88% against 50%, 50% and 53% in the other categories of boats. This is similar to numbers of accidents in the US [3].

The number of passengers on a boat does also influence the interests in the system: 1 or 2 passengers: 37%, against 71% and 100% with 2 till 5 and 5 and more passengers.

3.3.5 List of Requirement

R1. The system should be stand alone

R2. Prevent most common accidents, especially at low speeds (at high speeds the hull and the lower unit of the engine already causes severe injury)

R3. Does not give false signals

R4. Protect in as many cases as possible and should protect everybody (people in wetsuits, people which are not moving).

R5. Not be pseudo-safety, but an additional emergency system.

R6. Easy of use

R7. Easy to install by the boater itself (and remove)

R8. Universal and/or exchangeable

R9. Not require permanent changes to the boat or drive

R10. Reliable

R11. Not restrict performance

R12. Subtle (not as eye catching as most propeller cages) and lightweight

R13. Detect presence of humans at a sufficient distance so the system can react in time.

R14. Should run on the boat's power supply (12 V)

R15. Should automatically switch on and of with the engine (to prevent from exhaust ing the battery when drive is turned of)

R16. Durable and packaged for weather influences and (salt) water environment

R17. Sensors not effected by algae, barnacles and other marine growth

R18. Means of testing the system before take of (like smoke detector push button or automatically at start-up)

R19. Provides feedback that the protection mode is on and when the system inter venes

R20. Good costs/value rate, system should be worth its costs

For more explanation of the requirements and their origin see: Appendix 8.3 List of Requirements Origin and Explanation.

Design 4

4.1 Idea and concept generation and choice

4.1.1 Problem analysis

To prevent contact between a person and a running propeller I could think of three main principles. I can get rid of the exposed propeller by relocating or integrating the propeller (propellers of water-ski boats are located underneath the boat) or changing the way of propulsion (jet propulsion). I can mechanically prevent contact with the propeller by covering the propeller (permanent or in emergency situations). And I can take away the danger of the propeller by stopping its rotation. Another way could be warning the skipper for danger so he/she can prevent an accident from happening, but the reaction of the skipper would be too late in many occasions.
Thinking of possible solutions I came up with two main directions:

Prevention; prevent contact between the propeller and humans by permanently covering the propeller.

Detection; detect humans who are dangerously close to the propeller or are approaching the propeller followed by protection, perform a certain action like stopping the propeller or temporary covering it.

Prevention is a very reliable way and can be simple and relatively cheap. Another advantage is that, if designed properly, it can increase the boat's efficiency. There are many possibilities imaginable but existing designs often have lots of problems,

They: [2]

- Restrict Performance
- Guards themselves entrap people, injuries become more severe
- Increase zone of danger (Guards increase area of impact)
- Create unstable handling conditions
- Increase fuel consumption
- Are too expensive
- Detract from the appearance of the drive
- Engine emissions are increased due to the additional drag (engine has to work harder and creates more emissions)
- Why worry about protecting from a propeller strike if it occurs after they have already been struck by the hull and lower unit (gear case, skeg, etc.) at high speed before the propeller strike occurs.

Detection can be the solution to many problems with the existing designs which are based on covering the propeller. They could be easy to install with minor adaptations to the boat and do not influence the boats performance or handling. Problems with these

systems are that they are less reliable due to possible technology failure.
In the area of detection I again see two possibilities: One is detecting human beings using the biological properties of the human body like body heat, shape and electrical conductivity. Another can be to detect transmitters or tags worn by protected persons.

4.1.2 Detection concepts

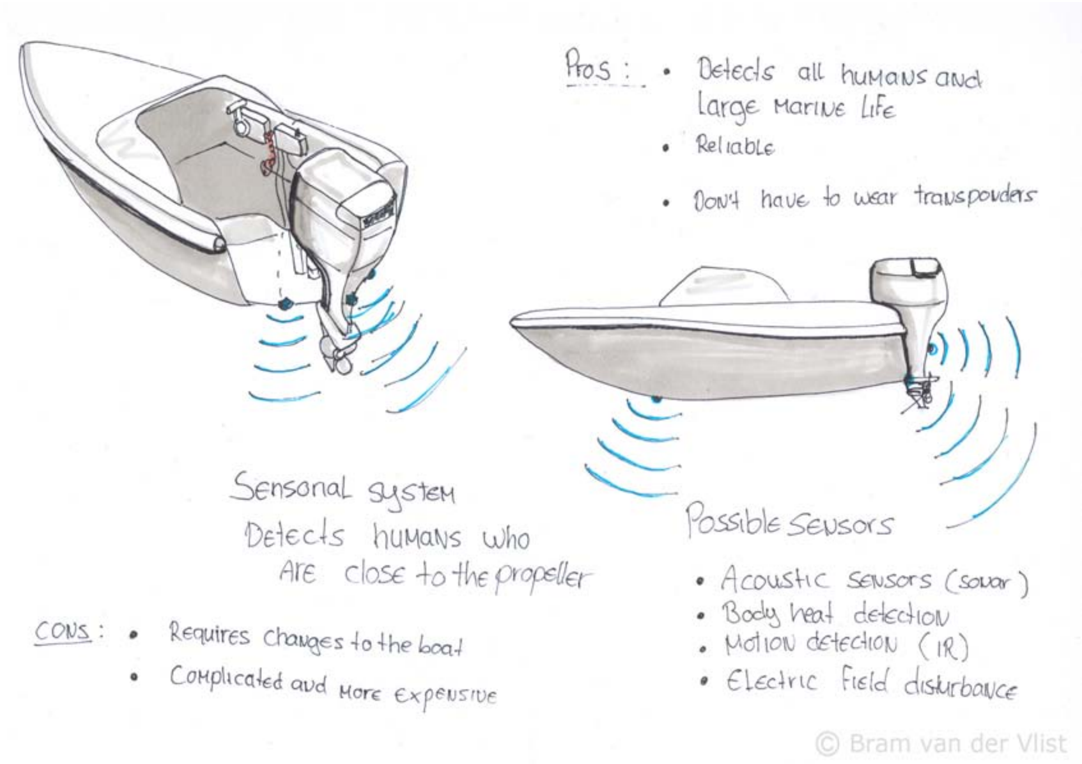


Fig. 4.1.2.1 Detection concept 1

Propeller guard with human body detection

Different types of human body detection sensors are placed on several locations on the tailpiece of the engine and the hull. These sensors are connected to a central control unit which processes the data and decides according to the data which action(s) is (are) performed. Possible actions are stopping the engine and/or sound an alarm. The control unit is placed next to the remote control of the engine and could use the lanyard ignition cut-off switch loop to shut down the engine.

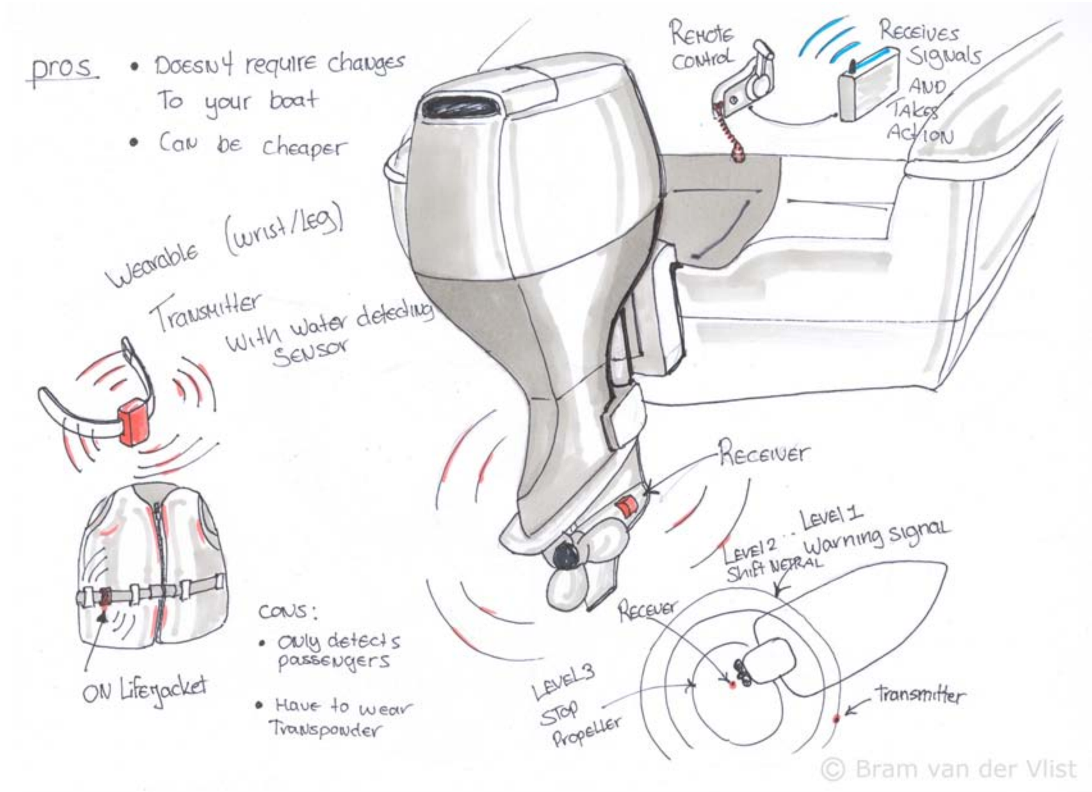


Fig. 4.1.2.2. Detection Concept 2

Propeller guard with a surveillance system that tracks the location of the passengers and the propeller.

The concept comprises a main control module that tracks the location of passengers wearing the transmitter and the location of the propeller (also tagged). The wearable transmitter is equipped with a water sensor which sends a signal to a control module when it detects water. If water is detected and the transmitter is approaching the danger zone, an alarm sounds and the skipper is warned for imminent danger. If the skipper doesn't respond the system will shift to neutral. If the transmitter enters the danger zone the engine is shut down.
The control module is placed next to the remote control of the engine and could use the lanyard ignition cut-off switch loop to shut down the engine. It is also connected to the gearbox to shift to neutral.

The main advantage of the latter is that it can be more reliable (less chance of false readings) but an important disadvantage is that it is a closed system; it only protects the wearers of a transmitter. Swimmers, surfers or occupants of other boars which are intentionally or unintentionally in the water, not wearing a transmitter are not protected.

4.1.2 Other Ideas

Other ideas that came up were improvements to existing applications or other variations.

Virtual propeller case

A system of electrodes surrounding the propeller area, measuring intrusion of human body parts. Once intrusion occurs the propeller is stopped immediately, reducing injuries.

PropGuard improvement

A version of the PropGuard of a conductor material. If the guard is approached until a small distance (millimetres) or is touched, the propeller is stopped, preventing from limb entrapment.

Detection could be done with several sensors like tactile sensors, motion detection, body heat detection and acoustic sensors. More about sensing technologies you will find in section 5.1.1 Existing Sensing Technologies.

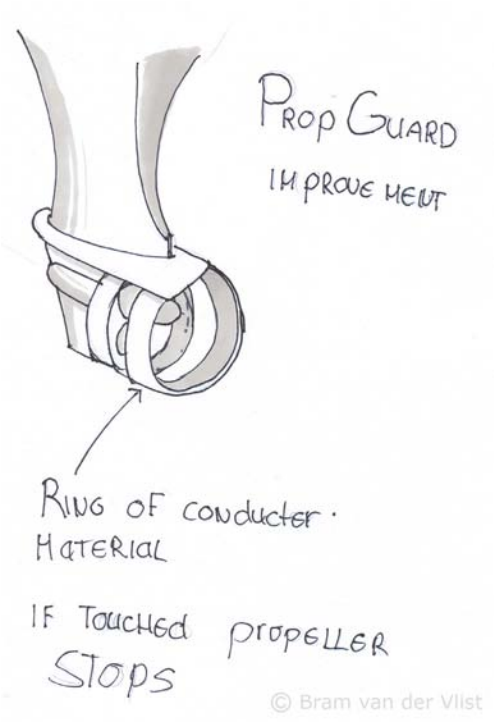
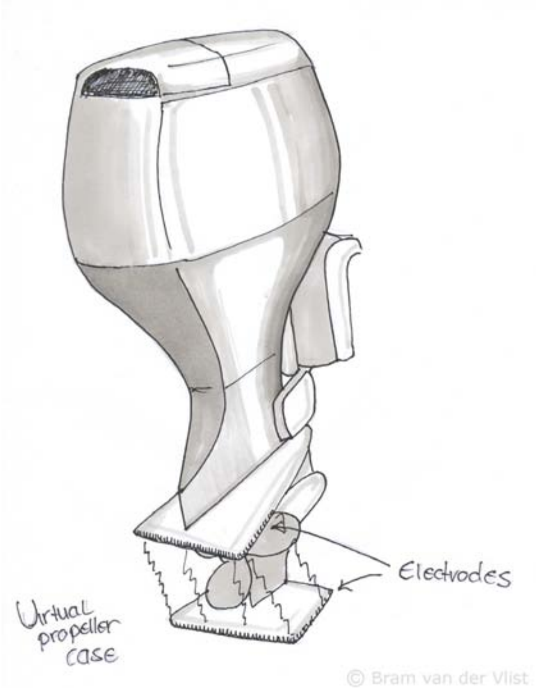
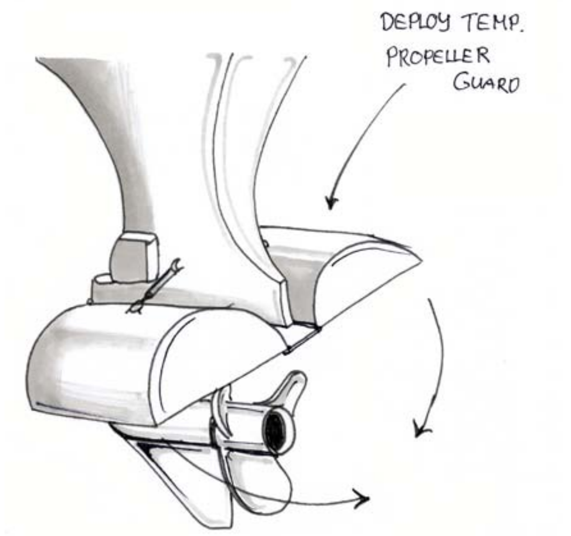


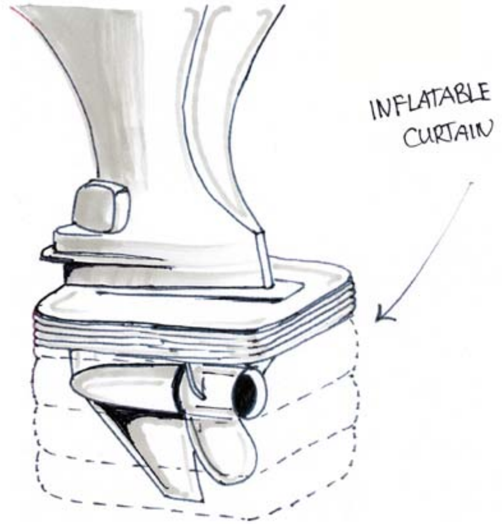
Fig. 4.1.2.2 PropGuard Improvement

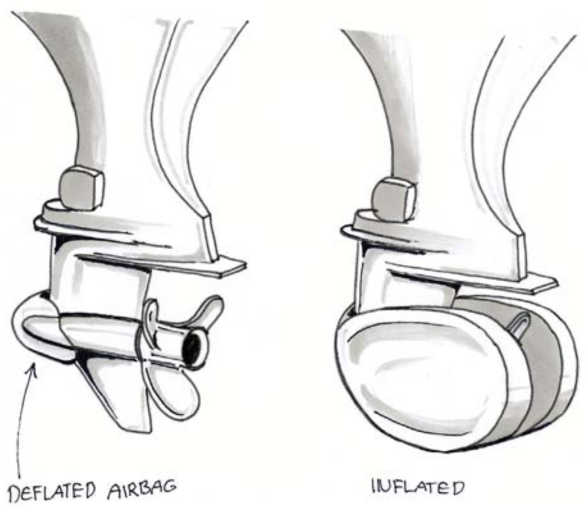
Fig. 4.1.2.1 Virtual propeller case

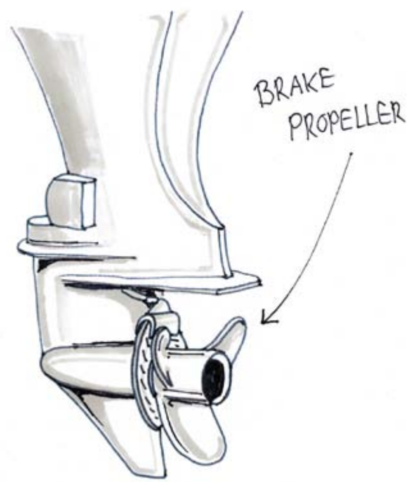


Protection ideas 4.1.3









Possible actions could be:

- Sound and alarm / blow a horn --> only as warning
- Inflate propeller guard (like an air bag) which covers the skeg and propeller --> slows down the boat and decreases handling
- Deploy a (mechanical) propeller guard
- Raise tail piece
- Push the victim away using a strong water jet
- Shift to neutral --> motor keeps running
- Stop or slow down propeller (braking)
- Stop engine and propeller (ignition cut off) --> use lanyard ignition cut off switch

Figures 4.1.3.1 trough 4.1.3.4: Ideas on how to intervene when danger is detected

4.1.4 Concept Choice

The choice between the two concepts of detection was a hard one. Partly due to the big difference in the level on which the solution solves the problem. The "detecting anybody" solution with the use of human body detection covers the entire problem instead of the "detecting tag wearers" solution which only solves a part of the problem. Though, lots of accidents happen with passengers being struck by their own boats and since I excluded propeller strikes at high speeds, passengers have an increased risk of getting injured. With the focus on water-skiers the disadvantage of the tag that has to be worn also decreases because water-skiers always wear a life jacket (not only for safety but also because you can hardly float in the water waiting to start without one). A tag could easily be attached to this life jacket.
I decided to go for the concept direction of detecting humans by detecting a wearable tag. For the protection I choose for shutting down the engine because it is the most easily installed and universal system. There might be other and better possibilities thinkable but I will shift my focus more on the detection side of the solution. Besides the reasons above there are some other important reasons, both concerning the design as the project opportunities.

Reasoning:

- more feasible to make reliable
- suits the "stand alone character" better
- less complex – less expensive
- sufficient protection in water-ski scenario
- requires less changes to the boat
- suits the project goals better
- more diverse design challenges
- more feasible in available time and with available expertise

Fig. 4.1.4.1 shows an overview of the marking of both concept directions with regards to the most important requirements (taken from the list of requirements see: 3.3.5 List of Requirements)

Selection criteria for applied technology	**Marking tags**	**Marking sensors**	**Reasoning**
Stand alone → measure of capability to work stand alone, minimal integration			Installation of various sensors and required monitoring of boat conditions makes it more suitable for integration
Should at a minimum prevent accidents during waterskiing			Are both suitable for protection during waterskiing people not wearing tag not protected
Minimum risk of false signals			Higher risk of false signals
Protection of people in many situations → not moving / wearing wetsuit / half underwater			Sensor system is more sensitive for influences of different situations
Not being influenced by environmental conditions → water conditions / other boats and objects			Sensor system is more sensitive for influences of different situations
Not be pseudo safety			
Easy of use			Sensor system more sensitive for failure and maintenance
Easy to install and remove			Sensor system harder to install
Not require permanent changes			Mounting of various sensors on hull and drive might require permanent changes
Reliable			
Runs totally in background, not requiring attention			
Not influence performance → additional drag etc.			Sensors can cause additional drag
Run on a boats battery			
Reasonable costs for the provided service			Sensor system relatively more expensive

Fig. 4.1.4.1 Concept Choice

Concept Development 4.2

After some extensive thinking, taking a lot of aspects into consideration I adapted the initial concept and defined the systems behaviour.
The final concept differs somewhat from the concept described above (4.1.1.2 Detection Concept 2). Instead of alarming the skipper in a dangerous situation (threshold value 1) and shifting to neutral if the skipper does not react, the system only warns the skipper. If the distance decreases below thresholds value 2 the engine is shut down.

4.2.1 System behaviour

The system has three different "inputs". There is the normal interface between boat and skipper comprising the steering wheel, throttle/gear handle and ignition. The additional interface to control the designed safety system and of course the distance measurement and immersion detection. All these inputs influence the systems behaviour. The detailed system behaviour is defined in the state transition diagram 4.2.1.1 System behaviour on the next page.

A brief explanation

The system turns on automatically when switching on the boats ignition. If the ignition is already switched on and the system is not (because it is turned off earlier) it can be turned on manually by pushing the 1/0 button. The system runs a quick system check, showing all control LED's and sounding the alarm buzzer. This allows the user to check if all these interface components work. The system also checks the correct working of its sensors and actuators. Once the check is completed the system can be either OK or report an error. In error mode the user can try to identify the error and perform a new test. If the error can be solved the system can turned of (the system could be brought in to the dealer for repair). If the system is OK it continues to its basic state, the protection mode. In the protection mode the user can shut off the system at any time by holding the 1/0 button for 5 seconds or perform a test if he/she suspects an error.
If someone approaches the danger zone and the drive is running and in gear the skipper is warned by an alarm and a visual signal. The skipper has time to assess the situation and take necessary actions. The alarm can be turned of by pushing the bypass button. The alarm stays off until the danger level changes. Once the person in the water is entering the danger zone the system shuts down the engine immediately. The system will also avoid the engine from being started while the person remains in the danger zone. If the skipper wants to start the boat because of an emergency situation he can bypass the system by putting it in bypass mode. The system remains in bypass mode until bypass mode is turned off again or the danger level changes. There is also the possibility for the system to intervene directly if suddenly the danger zone is entered (in case of entering the water near the drive left in gear or falling into the danger zone). The system can be turned off in every state by pushing the 1/0 button for more than 5 seconds. After the ignition is switched off and the system isn't used during 5 minutes the system automatically shuts down, preventing battery exhausting.

Threshold values

For a good and safe operation of the system the threshold values for the danger levels 1 and 2 should be about 3,5 and 2 meters. These values only go for travelling at a low speed, below 6 km/h. To make the system work at higher speeds these values should be increased in relation with the speed. Determining these values was very difficult; on the one hand there should be an ample safety distance to keep it as safe as possible. On the other hand it is not desired that the engine shuts down if you are at a reasonable safe distance. And for threshold value 1 for the alarm, it is not desired that the alarm goes off every time the boat gets near someone in the water.
The tag is worn at the waist, which is approximately the middle of the total body length. If you, for example have a body length of 185 meters your maximum body length is about 2,40 meters (including arms and feet). In the most extreme position, totally stretched with the arm or legs pointing in the direction of the drive, there is 80 cm of safety margin to the propeller. This would allow the propeller to stop within a half second if the boat is backed towards the victim at 6 km/h. I think that will be nearly sufficient but seen the unlikely chance this would happen at normal behaviour this safety distance is acceptable.

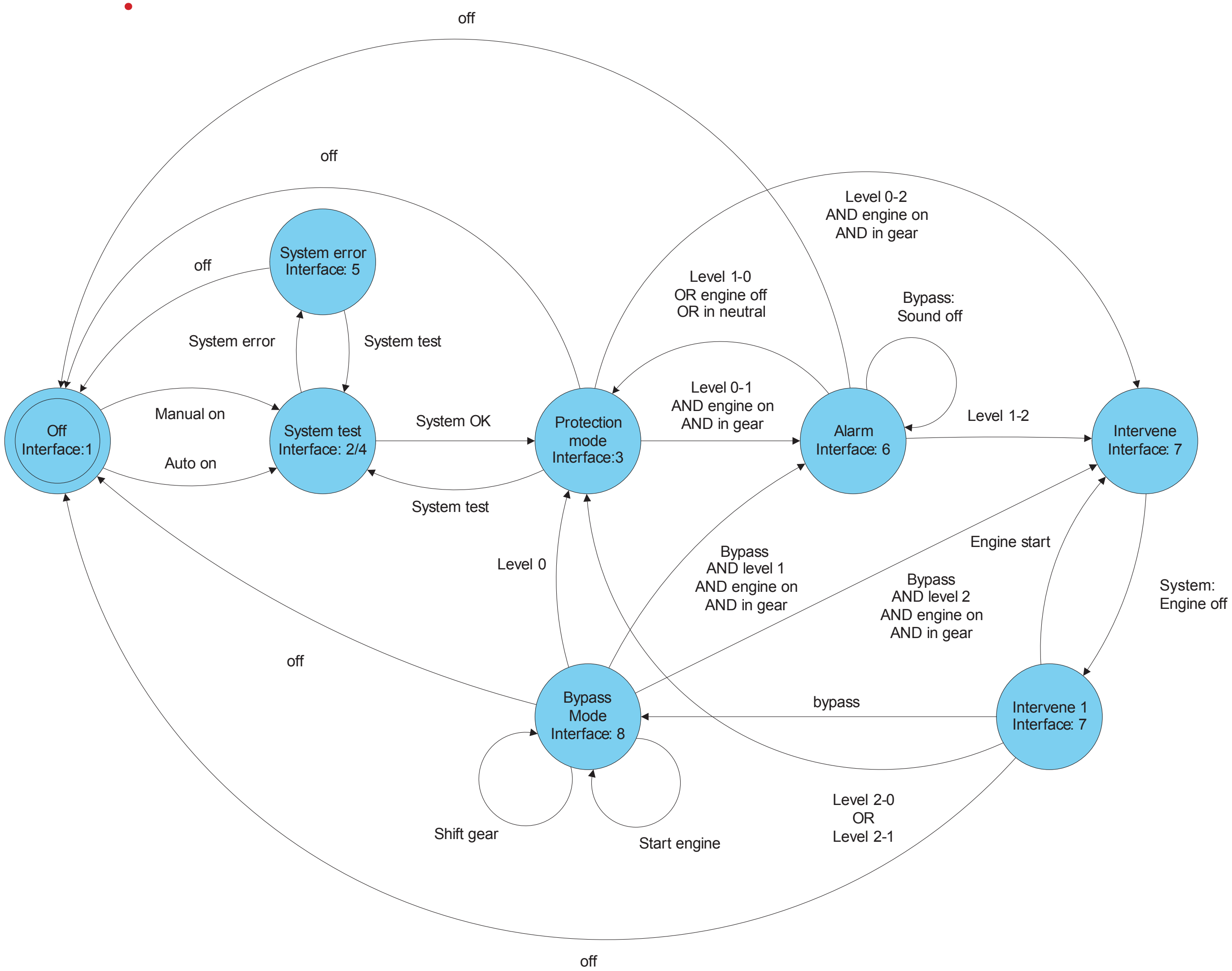


Fig. 4.2.1.1 System behaviour

Interface design 4.2.2

Although the system totally operates in the background and does not require attention of the skipper an interface is needed to make the user feel in control. The user should be able to shut down and activate the system manually and should be able to check the status of the system at any moment. The system should also provide feedback when the system takes action. The best and simplest way to warn the user in case of danger and when the system takes action is by means of sound. At the same time the system should provide visual feedback to inform the user about the reason for this alarm.
Another important issue is testing the system. When sensors or the alarm fail it is necessary to inform the user, otherwise the user would trust on an emergency system that wont work properly. I know from experience that it is important to know if the system is OK, because the fish finder and depth meter we have installed once had a defect alarm speaker. We always set an alarm at a certain depth to warn us when this depth is reached so we can take action to prevent the boat from striking the bottom. We discovered that the alarm was defect once we had already hit the ground. These kinds of situations are very dangerous with respect to my concept.
The system should be tested every time it is activated, and it would possibly also be desirable to make it possible to manually check the system. Once errors are detected it would also be helpful to provide a more specific feedback on what could be the problem (for instance a defect sensor).
I had different ideas about the interface, from having only one pilot light, only showing if the system is OK or not till a more extensive interface with error reporting. I decided to go for a minimal interface with 3 separate pilot LED’s and 3 buttons. The main principle was to show at any state if the system is “OK” or not. The user should be able to check this in only one eye catch. I think the best and simplest way to do this is to show a green light if the system is “OK” and a red light if it is not. If special attention is needed a flashing light should draw attention. On the picture below you can see the final interface design. It comprises three lights which decrease in size with the importance. It also has three buttons coupled to the lights. The main principle is that the button can change the state that is indicated by the corresponding light. To get a better idea of the working of the interface see: Fig. 4.2.2.2 Interface working.

Fig. 4.2.2.1 Final interface design

The numbers in the blue circles correspond with the numbers in the states of the state-transition diagram 4.2.1.1 System behaviour on the previous page. They indicate the status of the interface in each state of the state-transition diagram.

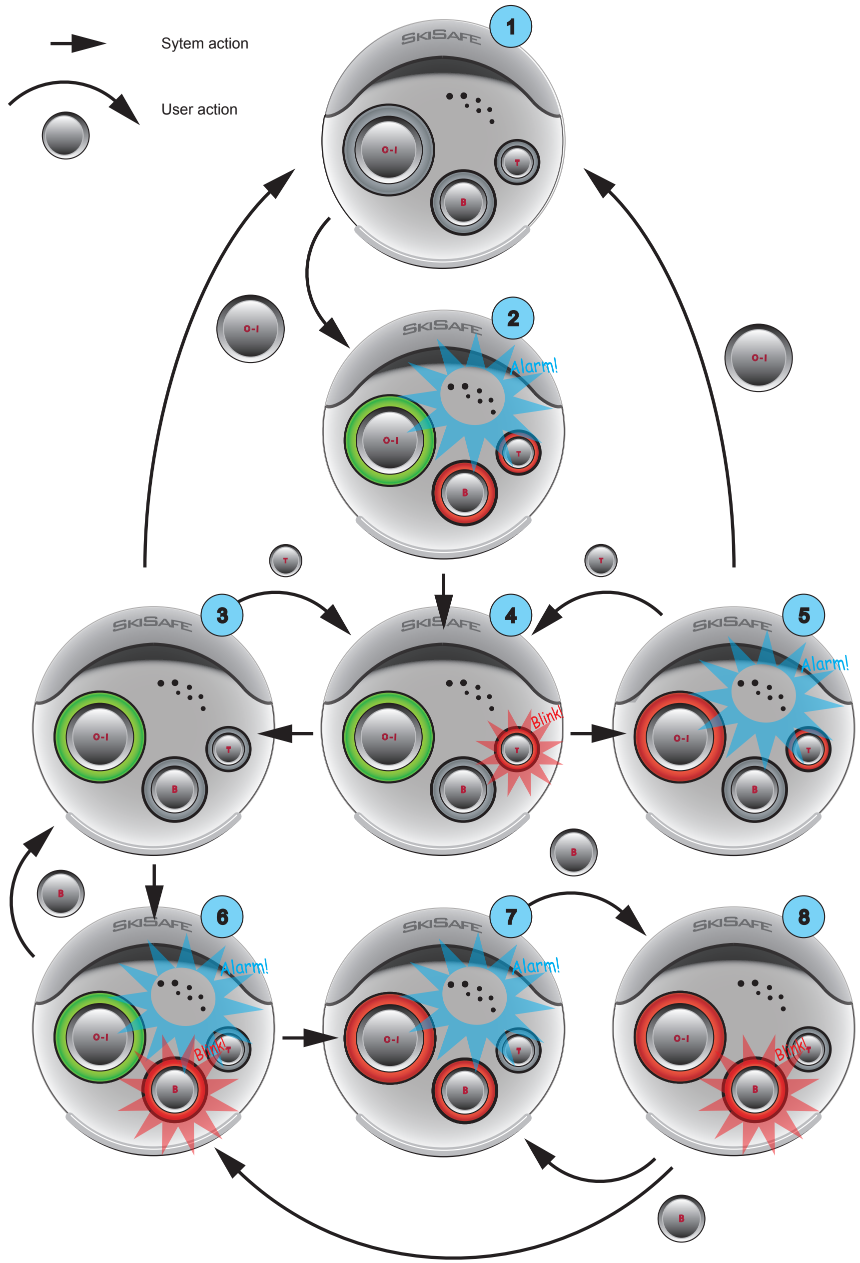


Fig. 4.2.2.2 Interface working

Design Problems and Solutions 4.3

Specific design problems I have encountered during the course of my project include: how to install the system on a boat with minor changes, where and how to wear possible tags or transmitters and how to (easily) shut down an engine or shift to neutral.

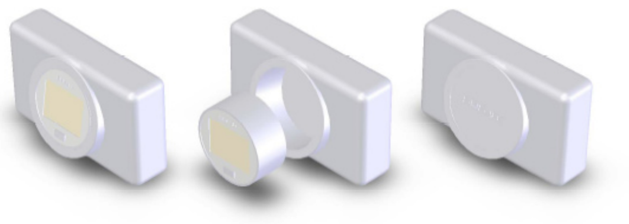
4.3.1 Shut down engine and check gear

The design problem of how to shut down an engine at a simple way is already solved. According to article 8.03 of the "inland navigation police regulations" (binnenvaart-politieregelement – BPR) every fast motor ship operating on Dutch waters should be equipped with an installation which, at interruption, should immediately stop or nearly stop the means of propulsion.
This means that almost every boat is equipped with a Lanyard ignition cut-off switch which shuts down the engine at interruption.
This lanyard switch is a switch connected to a safety loop located at the steering-gear which could be easily extended connecting the extension to the correct wires. On the internet and in every shop manual of the engine's manufacturer these wire colour codes can be found which makes it easily for boaters to install a system that uses this principle their selves. The system should only have an actuator like a relay that interrupts the ignition safety loop. Keeping this loop interrupted while danger remains also prevents the engine from being started again.
Another issue is how to check the position of the gear. The system should know if the drive is in neutral or in forward or reverse gear. A simple way to do this is to check the position of the gear handle by installing some kind of switch. A better solution would be to make the system compatible with the CanBus [11] control system to read data from the boats control system. Many new boats use this system and it might also allow later integration with other information like RPM and speed. Many devices and gauges can now "plug and play" using this control method.

4.3.2 Easy installation on boat

Above I described how a control module could easily be connected to the drive's build in ignition cut off system. Another issue concerning the installation on the boat is the placement of the physical product, the control module and the control panel. As the small collage on the next page shows (fig. 4.3.2.5 Dashboard layouts), the dashboard can have various shapes and configurations with sometimes limited space to install the system.

To design a shape that fits in all different dashboard configurations I thought of a modular system that could be installed in three different ways. It could be integrated in a dashboard which has some space left for additional gauges. It could be installed in a place holder paced the dashboard area or it can be installed as one system.



Figures 4.3.2.1 trough 4.3.2.3

Installation as one system
Detachable control panel
Control module separated

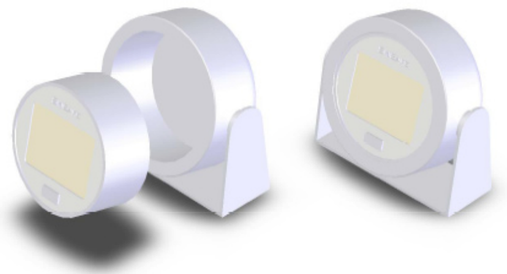


Fig. 4.3.2.4 Dashboard place holder

Another part of the system that should be mounted on the boat are the ultrasonic transducers. The transducers should be mounted at the rear of the boat in a certain radius of the propeller below the water surface. The transducers can be placed on the drive and on the hull of the boat. The best location for the transducers depends on the type of transducer (beam angle) and the type of boat. The transducers should be mounted in a way they cover at least the 180 degree angle from the back of the boat. Mounting on the boat could be done with glue; this would not require drilling in the boat or drive. The wires can be concealed with wire covers.

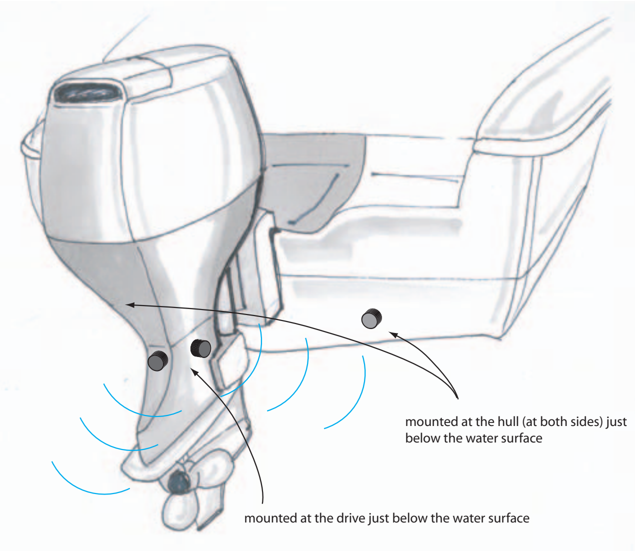


Fig. 4.3.2.6 Tranducer mounting

Fig. 4.3.2.5 Dashboard layouts

Wearing a Tag 4.3.3

To detect the distance towards the propeller and to detect whether the person is in the water or not, he or she should wear a sensor/tag. This sensor should be worn somewhere easy and at a place which is in the water when a person is. The pace should also be in the middle of the body, this is necessary to have as small as possible safety distance (see figures 4.3.3.1 and 4.3.3.2). The waist is a good place, it is almost always in the water and it is the central place of the human body. It is also easy to wear a tag there, attached to a belt (of a life jacket) or at the swimming trunks.

To design the sensor in a way it can be worn in the right place on several ways I have the following idea:

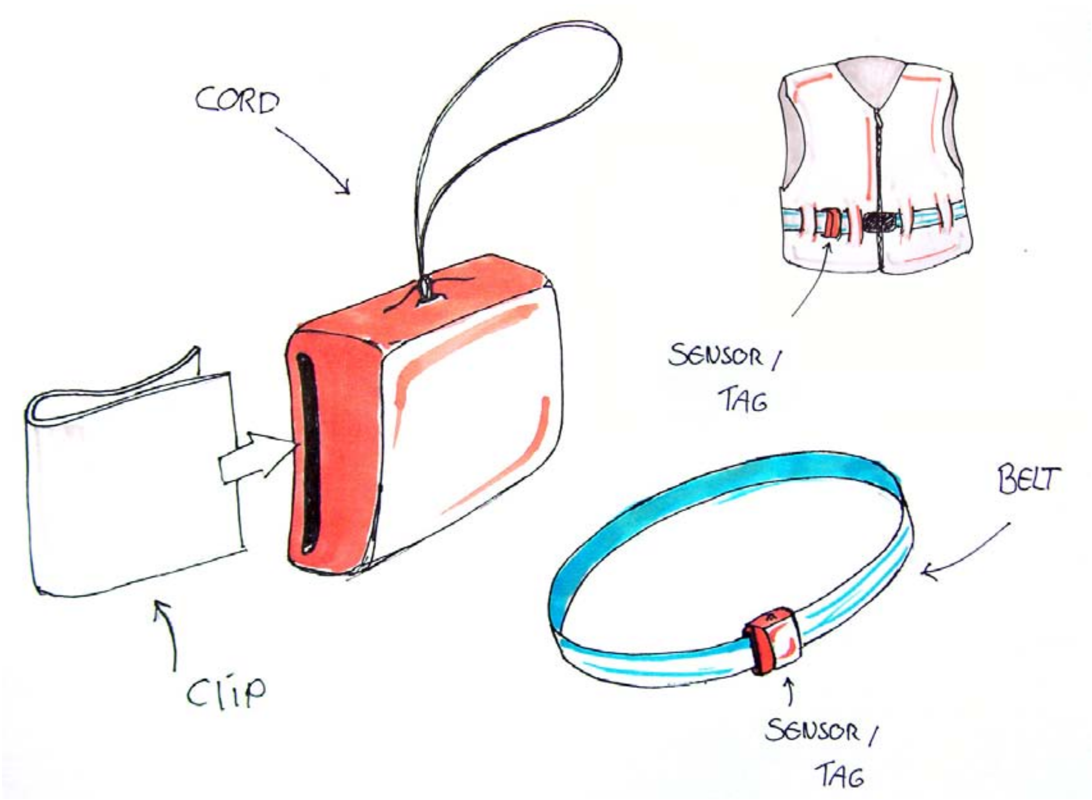


Fig. 4.3.3.3 How to ware a tag

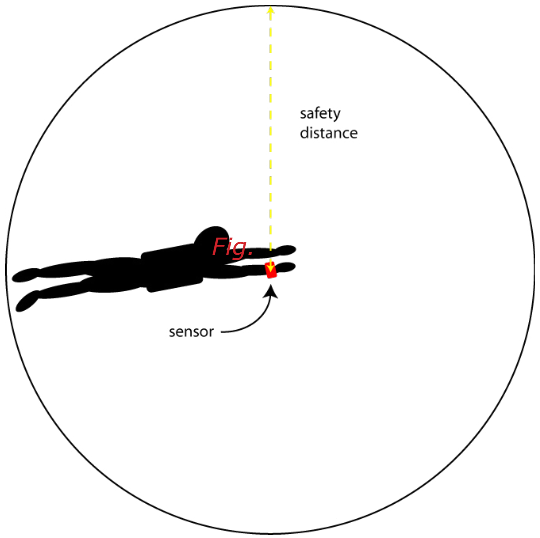


Fig. 4.3.3.1 Large safety distance

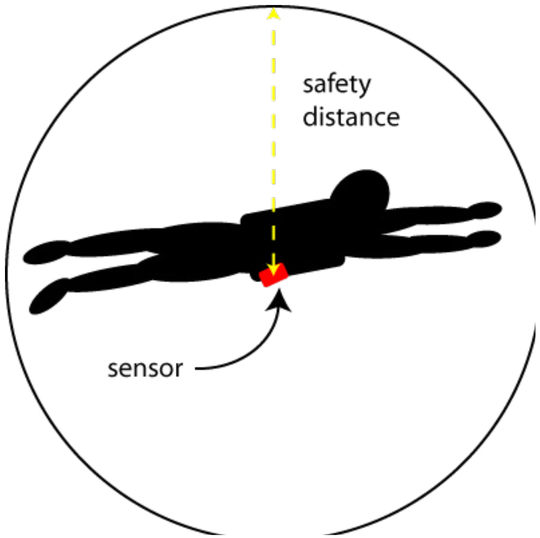


Fig. 4.3.3.1 Small safety distance

4.4 Physical Design and Aesthetics

Fig. 4.4.1 Tag design

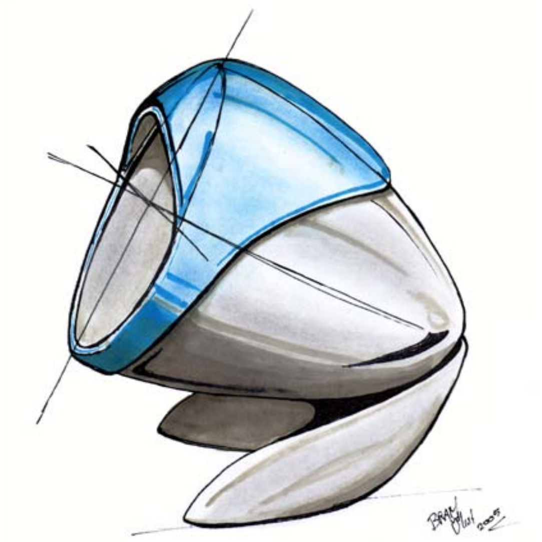


Fig. 4.4.2 Dashboard place holder design

Although it is not the main focus of my project, I think it is important to pay attention to the systems appearance. I performed three short form studies to give the visible parts of the system a physical shape. Besides the functional aspects of these parts I also tried to give the system a coherent identity and appearance.

The starting points for the form exploration where:

Round, friendly and dynamic shapes
Round gauge style
Presenting the interface
Coherent visual language

The interface I designed has a friendly and fanciful shape and configuration due to the circular shapes and asymmetric configuration. It is a circular shape so it fits the overall appearance of the dashboard, which holds circular gauges, better. It also gives the user the possibility to install the interface in an empty gauge place holder.

The dashboard place holder presents the interface to the user in certain angle. It features a sun screen to give the lights a better visibility. This sunscreen is made from a flexible material so it can be removed from the rest of the body to take out the interface if the user wants to install it directly into the dashboard.

I decided to change my initial plan to make the system modular, also allowing to install the interface and control module as one. In my opinion it would be best to have the interface in the dashboard area and not somewhere aside. The control module would be a black-box which should be build-in or concealed during the installation.

The tag comprises a flexible clip that holds the main body and the main body itself. The main body has a half spherical bulge which houses the ultrasonic transducer. The overall shape of the tag relates to the shape of a shield to emphasize the protecting function of the tag.

The final designs presented here have naturally been trough a path of shape exploration and development. In Appendix 8.7 Design Sketches you will find a collection of design sketches showing the development of the designs.

Technology 5

5.1 Current Issues

An investigation after existing solutions, patents and existing technologies has been done to find useful technologies and to get inspiration.

5.1.1 Existing sensing technologies

To find applicable technologies for sensing human beings, I investigated different types of human body detection methods based on detecting one ore more biological properties of human bodies.

Body heat

Healthy human bodies have a body temperature of 37 degrees centigrade. Because this temperature is higher then the normal temperature of water, humans in the water could be located using heat sensors. [US patent: US 6,676,460]

Possible problems and issues to deal with:
- False readings --> you might also detect a warm boat dock near your boat before you start your engine or detect warm exhaust-gases.
- Too small temperature difference (ΔT) --> body is 37 degrees water can be above 25.
- Low detection distance, temperature difference is very local

A possible technology to sense temperature differences is Infrared. This technology has some limitations and problems like the inaccuracy at low temperature differences and there are some issues I should investigate like using IR under water or above water.

Motion

Motion detection has one major problem, a swimmer might be motionless

Possible technologies to detect motion are:
- PIR-sensors
- Sonar
- Radar

Acoustic

Human bodies can also be detected by the difference in the reflection of (ultrasonic) sound.

Possible technologies:
- Sonar (underwater)
- Radar (not really acoustic but similar)

Disturbance electro- magnetic field / difference in conductivity

Human bodies can disturb an electromagnetic field and have different conductive properties than water.

Possible problems and issues to deal with:
- Low detection distance
- Different water conditions, different conductivity (salt water, pollutions)

Possible technologies:
- Capacitive sensors
- Galvanometric scanning --> needs strong signal processing or filtering to remove unwanted measurements (bubbles, different water conditions)

Visual

Human bodies can also be detected using optical sensors sensing the human body shape.

Possible problems and issues to deal with:
- Limited sight underwater

Possible technologies:
- CCD camera: optical recognition sensor with human shape recognition (several techniques and approaches available). RoboCup Rescue Scenario [10], Defending the fleet in harbour, Swimming pool observation system.
- Radar
- Laser

Tactile

Solid (human) bodies can be detected using tactile sensors.

Possible problems and issues to deal with:
- Limited detection distance (should be attached to the boat)
- Detects all kind of solid bodies and the ground

Possible technologies:
- On off switch attached to a feeler
- Magnet attached to feeler and magnetic sensor attached to the boat
- Bend sensors
- Optic fibre --> light path in the fibre shortens or lengthens with bending

Similar applications 5.1.2

Research has been done after technologies used to sense human (being) underwater in different but similar situations including: Search and Rescue human bodies after a disaster: RoboCup Rescue Scenario [10], Navvy harbour anti terrorism defence system: Defending the fleet in harbour, Swimming pool observation system: Poseidon

Basically I can conclude that these systems differ too much from the situation I am dealing with. The swimming pool observation system and the harbour security are static situations unlike the dynamic situation I am dealing with. The swimming pool observation system works in clear water instead of turbid water. There could be used Infrared cameras instead, but these are very expensive. Basically all three systems are very high-tech and the technologies way too expensive to use in a consumer product.

I also conducted a small literature search and wrote a literature review about existing human body detection methods. The conclusion of this literature search was:

“The literature described above provides different ways of human body detection and recognition for several applications. Most approaches are video based which means that they work analysing video streams. This approach immediately causes a problem in the application I am dealing with. In this situation persons are most of the time half underwater. These camera based systems will not work underwater because of high water turbidity. Cameras might be replaced by infrared cameras and use similar image processing software as used in above water situations. Because humans are only partly underwater, human body part detecting and reconstructing systems as described by Mori, G [21], Panagiotakis, C [13] and Ruiz Del Solar [12] are most suitable. Other suitable possibilities are the use of pyroelectric sensors [15] and electromagnetic micro waves travelling trough the water and change in reflection characteristics when a human body is detected. [11]”

For the full review see:
http://www.student.tue.nl/h/b.j.j.v.d.vlist/LiteratureReview2005Vlist.pdf

5.1.3 Immersion detection sensor

My concept comprises a system which measures both the distance from a person (wearing a tag) towards the propeller and whether the tag is immersed in water. The reason for measuring immersion and not just the presence of water is the involvement of water splashes (due to waves) and rain. Just detecting the presence of water would cause the system to give false readings.

As a starting point for my search for sensors which detect immersion I looked into a similar application, namely automatic life-jackets. These automatic life-jackets are deflated (making them easy to wear) in normal state and are inflated once the wearer falls into the water. Most of these life-jackets are equipped with a cylinder filled with compressed air or CO_2 which inflates the jacket once a water degradable element is dissolved. This principle will most likely not work in my situation because the water sensitive element should be replaced after every use. In contrast to the desired sensor, this should detect immersion time and time again. There are life jackets which work electronically, this works by the reduction of resistance between two external electrodes once both immersed in (salt) water. The most reliable system available is a system that uses a hydrostatic valve which let pass water at the hydrostatic pressure of 10cm H2O (10 cm of immersion). Once the water passes the valve, it again dissolves a water sensitive element. For my application this water sensitive element could be replaced with a water sensitive sensor, or pressure could directly be used for measuring immersion by means of a pressure sensor.

Immersion detection possibilities

Float
A floating object attached to a displacement sensor (active, continuous measurement) or a floating object which closes a switch when a certain level is reached (passive, switch). This principle is direction related but this could be solved by mounting the float gyroscopic and increase the weight of the bottom so it stays down.

Hydrostatic pressure
Hydrostatic pressure sensors could be absolute of relative (differential sensors). An absolute sensor measures the absolute pressure normally 1 atmosphere. A differential sensor measures the difference in pressure. With one port sealed or vented to atmosphere it measures the pressure relative to atmosphere. The differential pressure is directly proportional to the weight of the water column.

Ways to measure hydrostatic pressure

Membrane sensor: measures the difference in pressure of both sides of a membrane. The deformation of the membrane is coupled to a change in resistance. This could both be an active sensor which continuous measurement or a passive pressure switch, closing a contact at a certain level.

Pressure sensitive film: a film which changes in resistance due to pressure changes (active)

Deformable rubbers: there are deformable rubbers available which change in resistance due to deformation. (Active)

Piezoelectric materials: piezoelectric crystals generate an electric charge over the endpoints when they are pressurised in certain directions. (Passive; generates electric charge, reading needs power)

Other ways to use pressure

Hydrostatic valve: like the life jacket described above.
Piston: use a piston to activate a switch mechanically.

Electrical Capacitance
Capacitive water level measurement: metal rod in a cylinder, the metal rod and the cylinder act as capacitor plates. Active, could be used as both continuous measurement as point measurement.

Acoustic/optic
Sonar: ultrasound echo range can be used to measure water level (like depth and fish finders installed on boats). Transmitter and receiver can also be placed opposite one another across a gap. The presence of water in the gap can then be detected (the same principle can be used for light or IR).

Heat
An object could be heated and once the heated object is immersed the temperature drop can be measured using temperature sensors.

Water presence
Water could be detected using a water or rain sensor. These sensors consist of a matrix of contact points which are electronically connected by the contact of a water drop.

For the application I intent the sensor to use for, a membrane pressure switch would be best. This switch should cover the appropriate range. I found a suitable membrane pressure switch in the range of 1,2 – 8 mbar, equal to 1,2 to 8 cm H2O.This switch uses the same principle as the membrane sensors, only the strain gauge is replaced by a contact switch which closes as the membrane is deformed enough. The switch value is adjustable with an adjusting screw.

I bought the pressure sensor and implemented a simple test circuit, in which the pressure switch switches on a battery powered LED when there is enough depth detected. It would be best if there was some sort of pressure transmission between the sensor and the water so the pressure port of the sensor is not directly exposed to water. This could be done by attaching a small bellows to the port. If it gets submerges the air in the bellows will be compressed and the pressure sensor will switch. I quickly prototyped this (see picture below) and tested it underwater.

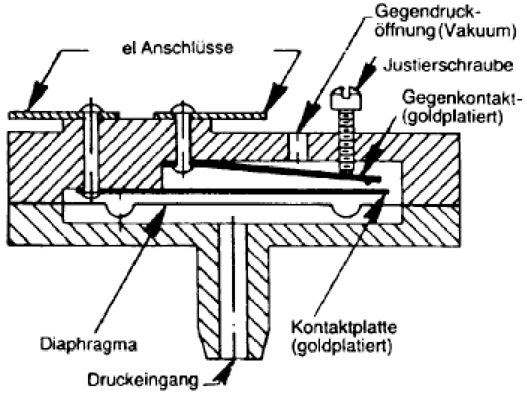


Fig. 5.1.3.1 Schematic cross-sectional diagram of the pressure switch

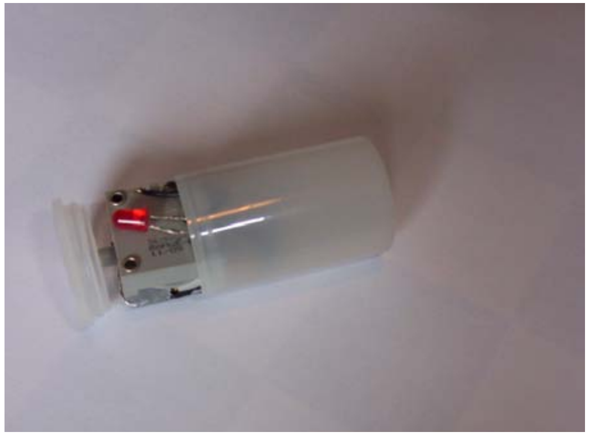


Fig. 5.1.3.2 pressure sensor test

5.1.4 Distance measurement

There are several thinkable technologies to perform distance measurement with. Technologies that use radio waves, ultrasonic waves and several optical technologies like infrared are thinkable, but the situation in which the system should perform is a very difficult one.

Technology choice

What I need is a technology that can measure distance between a wearable tag and a fixed point (or maybe multiple points) on the rear of the boat or drive. It should work in a range of approximately 0,5 – 5 meters with a precision of about 10 centimetres in the range of 0,5 – 2,5 meters. The tag will be under water or alternately under- or above water. Having a line-of-sight is not continuously possible and there could be obstacles between both points.

Optical
Because there is not always a line of sight optical distance measurement technologies like infrared could not be used.

Radio frequency
RF technologies like passive RFID-like tags, tracking tags which they use for tracking animals, tags used to find skiers buried under snow due to avalanches and maybe low range FM transmitter and receivers measuring distance in relation with signal strength or time-of-flight could be thinkable.
Passive RF tags would be the best solution because these tags are powered by the radio waves transmitted by the transmitter. This could be an excellent possibility to detect if someone is in range (in the danger zone) without powering the transmitter the person is wearing.
However, the short range and the required high precision make it very difficult to use these technologies. RF waves travel with the speed of light (3*108 m/s) so using time-of-flight measurements on such a short distance is nearly impossible. It would need very fast and powerful processors to do the timing and even with good processors, varying temperature and battery power and low cost components will make it very difficult. It might be possible but it would certainly be too expensive for consumer products.
Using RF signal strength might be a better solution but again on such low distances and thousand-and-one other causes of signal strength variation than distance, this does not seem to be a reliable option.

Ultrasound
Ultrasonic technologies are more suitable for these short distances and can be used both above and below the water surface. Travelling speed of ultrasonic (sound) in air is 340 m/s and in water 1500 m/s. This slower speed than RF makes ultrasound very suitable for low distances. The measurement should be totally above the water or totally underwater to make it reliable. Ultrasonic distance measurement above water is direction sensitive and obstacles between transmitter and receiver will reflect the pulse and spoil the measurement. Underwater the ultrasonic waves spread in a much wider angle and

especially at such a short distance direction would not be a problem. Also obstacles are less troublesome because the ultrasonic waves can travel "around" them. Large flat obstacles (like wakeboards) could still be a problem.
There are the so-called omni-directional transducers which produce a 360 degrees ultrasonic wave, which will improve the systems performance.
Another disturbing factor can be the cavitation caused by a running propeller. But at low rpm's it might not cause significant disruption at all.
Because ultrasonic technologies seem to be the only promising technology and is also easier to realize within this project, I decided to implement this way of distance measurement and investigate how it will perform underwater and near a running propeller.

Possibilities within ultrasonic distance measurement

There are several approaches to do ultrasonic distance measurement and several combinations of RF and ultrasound.

Hybrid
In cases where, beside the distance between receiver and transmitter, also is the need of a data connection (for identification etc.) there can be used both ultrasound and RF technologies. These hybrid systems (like Cricket [14]) send concurrently a RF signal (with data) and an US pulse. Because RF travels way faster than sound the US pulse will arrive later than the RF signal. The difference in time between both signals can be used to determine the distance using a time-of-flight measurement (Fig. 5.1.4.1 Hybrid 1).

Another possibility would be to drive an ultrasonic transducer circuit at a distance, using a RF connection. In this case the one side would transmit a RF signal which is answered by the receiver by transmitting an US pulse. Again the distance can be determined by performing a time-of-flight measurement. (Fig. 5.1.4.2 Hybrid 2) For these hybrid circuits the ZigBee [12] protocol might be very suitable. ZigBee is a reliable, cost and power efficient wireless technology which is very suitable for wireless sensor systems.

Ultrasound
A good way to perform distance measurement between two ultrasonic transducers is doing a round-trip-time measurement. Transmitter/receiver couple A sends a pulse to transmitter/receiver couple B. B waits for a fixed period of time and returns the signal to A. The total TOF can be converted into the distance.
The delay that B waits before it returns the signal makes sure that waves which are reflected do not interfere with the returned signal. (Fig. 5.1.4.3 Ultrasound)

The simplest way to do the distance measurement is with using only ultrasound.
I decided to prototype this solution because it is most feasible with the available resources, within the available time.

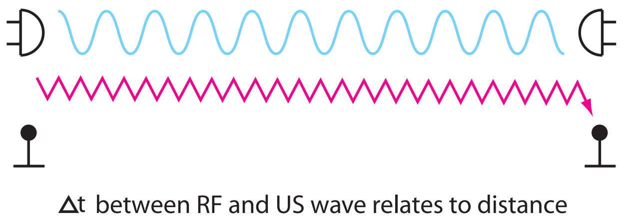


Fig. 5.1.4.1 Hybrid 1

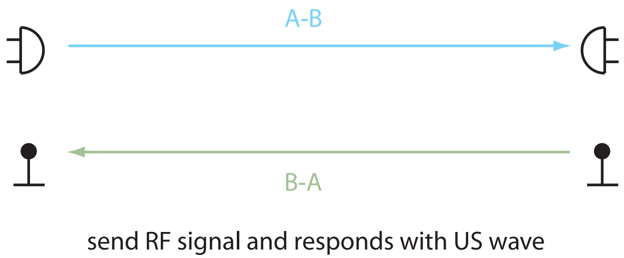


Fig. 5.1.4.2 Hybrid 2

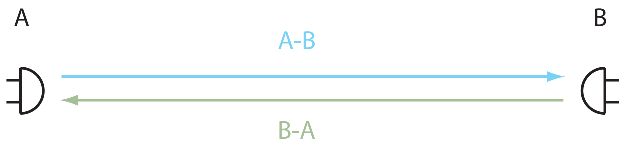


Fig. 5.1.4.3 Ultrasound

Building a simulation

First of all I had to select usable ultrasonic transducers. The best would be low cost transducers suitable for underwater use with a wide beam angle or omni directional transducers which create a 360 degree wave. Because my focus was on building something working which simulates the working of my system I used two water-resistant ultrasonic transducers which were available at our faculty's electronic workshop. My plan was to first make it work with air as medium and once working, to test it underwater. Although the test would naturally not be totally realistic I think it will be a good learning experience.
The transducers I got are 40 kHz Prowave 400ET/R180 water-resistant ultrasonic transducers with a beam angle of 30 degrees. Although these transducers are water-resistant, they are not specifically designed for underwater use but for outdoor use and use in humid environments.
My plan is to build driver and amplification circuits which could be controlled using a PIC microcontroller. The TOF measurement will also be done with a microcontroller.

Circuit design

I searched some provided documentation and the internet for circuit designs for similar transducers. I found a design of an ultrasonic range finder on a hobby electronics web site [13] on which I based my circuit design.
My design is different in working but the circuits to drive the transmitter and amplify the received signal can be used from the example. After having an idea of the working of the example circuit I designed a suitable circuit and selected and collected the required components.

For the circuit drawing see Appendix 8.6 Circuit Drawing

Circuit explanation

Receiver circuit:
The receiver circuit amplifies the signal received by the transducer a 1000 times in two stages, one time 100 times and one time 10 times of amplification. For this amplification I used two low-noise operational amplifiers with a high gain bandwidth product (25). After the signal is amplified the signal is rectified using diodes.

Transmitter circuit:
The transmitter circuit makes sure that the 40 kHz block signal produced by the microcontroller is transmitted to the transducer with sufficient electric power. The use of two inverters in parallel increase the transmitted electric power. The power supplied to the drive circuit is +9V the transistors are used to control this circuit with the +5V output of the microcontroller.

Switching circuit:
To make it possible to do both transmitting and receiving of a signal with only one transducer I used bilateral switches to switch between transmitter and receiver mode using the PIC.

Controlling the transmitter and receiver circuits

Now that I have two identical transmitter/receiver circuits I should control them and perform a time of flight measurement using a PIC microcontroller. The circuits have 3 inputs and 1 output. I need to send a 40 kHz pulse to the transmitter circuit; this could be done with a normal port defined as output. To switch between transmitter and receiver mode I can also use two normal ports making one high and the other low for transmitter mode and the other way around for receiver mode. For the output of the receiver circuit I will need a special port which can be configured as capture port. This build in capture function can stop the build-in timer once it captures an input change. This only goes for the fixed transmitter/receiver circuit which does the timing, the wearable transmitter/receiver circuit should only wait a certain delay after a signal is detected and return a 40 kHz pulse.

Calculating distance

The count value of the timer which is stopped by the capture operation is proportional to the travelled distance of the ultrasonic wave.
To convert the count value to a distance the following calculation should be performed. As example I will do the calculation of the 1 meter distance. The time the sound wave will travel 1 meter round-trip is: 2/1500= 0,001333 s = 1333 us. As the internal timer counts at 1us per count the counter value will be 1333. To get from time to distance in cm the value of the counter should be divided by 13. So when the counter is stopped at a value of 4000, the distance would be 4000/13 = 308 cm.

Testing

So far I didn't get the entire system working because I had some practical difficulties with the PIC. Though I have both transmitter/receiver circuits fully working. To test the circuits I connected a wave generator to the input of the transmitter circuit and connected an oscilloscope to the output of the detection circuit. See Picture 5.1.4.7 Electronic circuits test. Before the date of my final presentation I will try to get the full simulation working. And perform a small performance test with it.

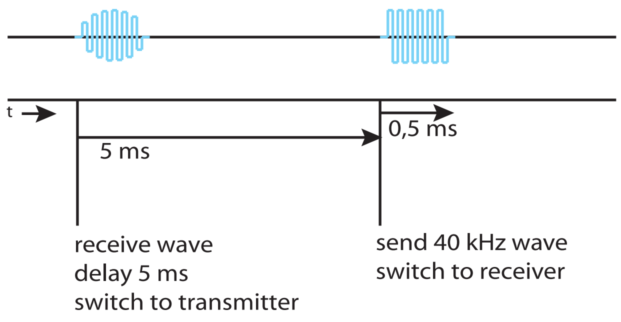


Fig. 5.1.4.5 Routine circuit wearable

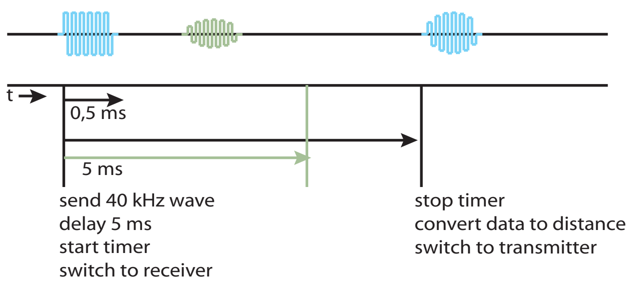


Fig. 5.1.4.6 Routine circuit boat

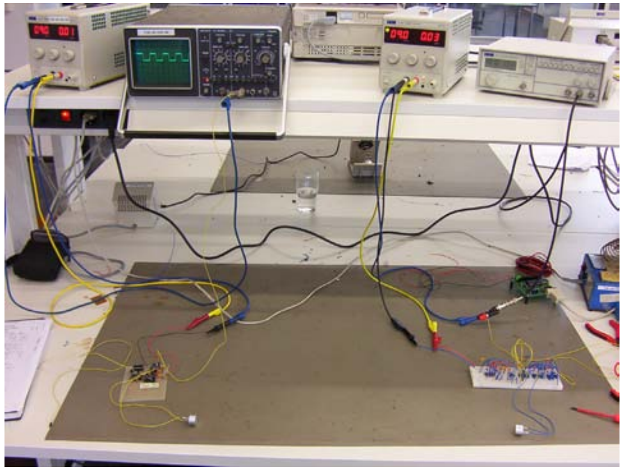


Fig. 5.1.4.7 Electronic circuits test

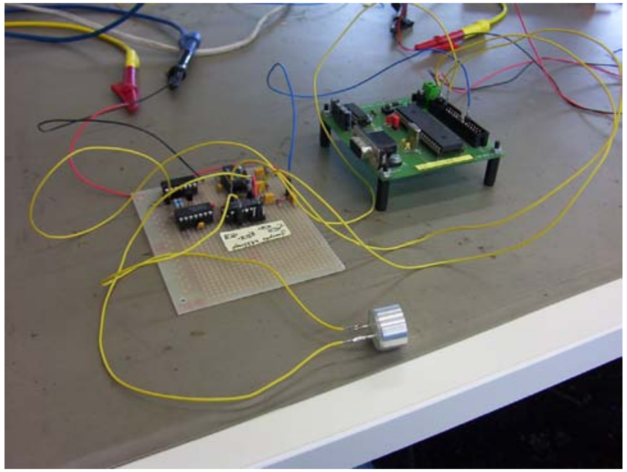


Fig. 5.1.4.8 Circuit connected to the PIC

Influence technology choice on working of the design

The use of the ultrasound round-trip-time measurement influences the systems performance and causes some limitations.
The use of round trip time measurement makes the measurements quite slow. Because the system has a built in delay the time between successive measurements, it is somewhat larger that for instance using the hybrid technologies.
This could make a difference in response time of the system shutting down the engine. I cannot say if these little differences (milliseconds) in response time have any significant influence on the systems performance.
Another problem I foresee is the fact that the distance towards the propeller can only be determined once the tag is submerged. It would be better to already know the distance towards the propeller making sure that if someone is in the danger zone and enters the water the system immediately responds. There are solutions thinkable for this problem like adding an above water ultrasonic transducer which measures the distance while someone is above the water.

Power supply

The circuits I designed run on a 9 volts power supply. For the one that is installed on the boat this would not be a problem, it could just use the boat's battery. The circuit inside the wearable tag should be powered with a 9 volts battery. To save battery power, the wearable tag will not be activated until it is in the water. This could be simply done using the pressure sensitive switch. There should also be a way to warn when the battery power is low, for example integrating a LED which turns on when battery power is low. Another, better solution would be to have a wireless data connection with the tag. Distance measurement could then be done using one of the hybrid technologies described above. If the battery runs low the tag could send a signal to the control unit which could warn the user by reporting an error. Again the pressure sensor could be used to send a signal and start the measurement. The batteries could be charged on board of the boat or at home. This charger could use induction technologies to charge the batteries while they remain inside the tags.

Conclusion and possible improvements

The best way to do the distance measurement in the final design would be with a hybrid technology instead of the ultrasound technology I used to build the working simulation. Having a RF data connection and using ultrasound to measure distance would be most suitable. This data connection allows the system to check the status of the transducers and the battery and report an error to the user if there is a failure. It will also speed up the distance measurement.
The travelling speed of ultrasound in water changes as temperature does, due to the agility of the molecules. With the change of travelling speed the time-of-flight also changes. To improve the precision of the system there could be a temperature sensor embedded in

the system to change the travelling speed variable.
Besides the water temperature the speed of the boat also influences the measurement. The speed of the boat is also important as it comes to the frequency of successive measurements. At low speeds the delay between the measurements can be larger that a higher speeds. Also for the behaviour of the rest of the system speed can be important.
Improvements to the systems behaviour can also be done by taking RPM and speed into account when the system decides to intervene or not to intervene. There is a standard developing in communication between marine drives and accessories like speedometers etc. called CanBus [11]. The later versions of my design could use this standard to communicate with the drive, for checking speed, RPM but also to check the gear’s position.

6 Conclusions

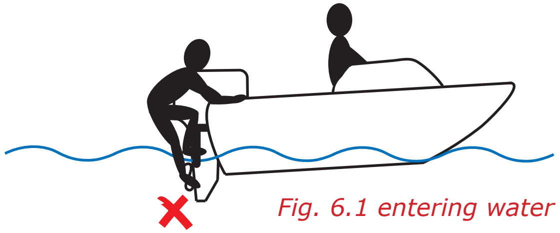


Fig. 6.1 entering water

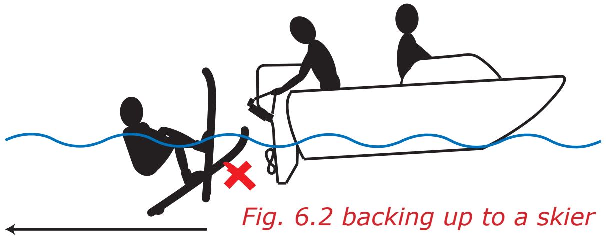


Fig. 6.2 backing up to a skier

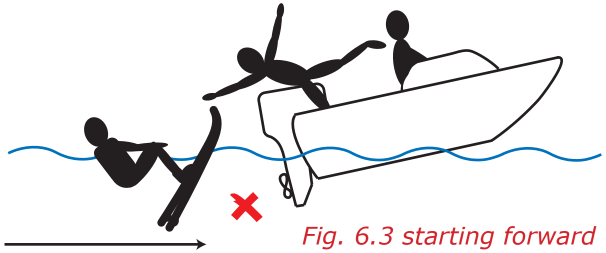


Fig. 6.3 starting forward

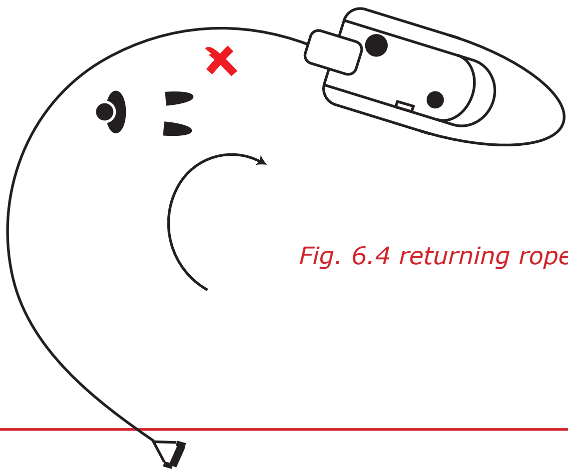


Fig. 6.4 returning rope

Looking back on the project, the mayor questions to answer are: does my design offer protection in the scenario I took as a starting point and how could the protection be improved in the future.

Let's take a look the water-skiing scenario from 2.3.2.

Entering water

In case of entering the water at the rear of the boat with a running propeller protection is not guaranteed. The system will only shut down the engine once the waist is in the water. Using the swim ladder this usually is the case but there are lots of other possibilities. Because the propeller is immediately shut down after entering the water with your waist it prevents from injury while swimming away from the boat.

Backing up to a skier

Backing up to a skier already in the water is protected by the system

Starting in forward direction

Starting the propeller if someone is in range is protected. Falling overboard at the rear of the boat is only protected if the victim does not get in contact with the propeller before his waist is submerged and the propeller is stopped.

Returning rope

The system does protect in case of returning the rope to a skier and the boat gets too close to the skier. It will also prevent from hitting the skier if he is outside the danger zone but wind and waves would bring the rear of the boat and the skier closer together.

In the other scenarios the system will also increase safety. In the case of swimming around the boat with a running propeller the system provides the same safety as with a skier being in the water. I case of falling overboard the system might not be capable of stopping the propeller before impact.
Once the system with the parameters as it was designed would be fully working with none or minimal risk of error, tests should be done with many possible scenarios. In the cases the system does not work there could be searched for solutions. I think that making the system more "intelligent", taking speed, RPM and other variables into account could improve the safety and user friendliness of the system. This could minimize unwanted intervention of the system.

Safety can also be broadened to make the system more open, instead of the closed system it is now. I can imagine that if systems like this would be used on a wide scale you could think of developing separate tags for divers and swimmers, so they can also protect themselves. Better would be to switch to the other proposed concept of detecting human bodies. If systems like the Poseidon swimming pool safety system I mentioned before could be simplified, adapted for use in turbid water and can be produced at acceptable costs, boating could be really made safer. Also education and using your common sense increases safety, but there will always be unexpected or unforeseen situations that will cause injury and even with a decent safety system accidents can never be excluded.

Although my project doesn't provide a solid solution to the problem I think I did a useful contribution to the search for a solution. It provides another approach to tackle the problem and might inspire other designers, engineers and maybe even drive manufacturers to develop a good solution.

7 References

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Appendices 8

Appendix 8.1: Contact information

Appendix 8.2: Questionnaire

Appendix 8.3: List of requirements origin and explanation

Appendix 8.4: Existing solutions

Appendix 8.5: Terminology

Appendix 8.6: Circuit Drawing

Appendix 8.7: Design Sketches

8.1 Contact information project participants

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Questionnaire 8.2

Online Enquête Bootschroef veiligheid

Algemene inleiding

Ik ben een derdejaars Student Industrieel Ontwerpen aan de Technische Universiteit van Eindhoven. Voor mijn ontwerp project ben ik bezig met het ontwikkelen van een boot-schroef veiligheidssysteem voor de plezier vaart. Ik richt me hierbij specifiek op snelle motorboten met een buitenboordmotor of een hekdrive.
Bij ontwerp projecten zijn de meningen van de toekomstige gebruiker erg belangrijk om tot een resultaat te komen wat inspeelt op de wensen en eisen van de gebruiker. Daarom deze online enquête.

Wat is uw leeftijd?

Wat is uw geslacht?

In welke provincie/regio woont u?

Wat voor een type boot heeft u?
- Snelle motorboot tot 7 meter
- Snelle motorboot vanaf 7 meter
- Snel motor jacht

Wat voor een aandrijving heeft uw boot?
- Buitenboord motor
- Binnenboord motor met hekdrive
- Binnenboord motor met schroefas en vaste schroef

Met hoeveel opvarende (inclusief uzelf) vaart u meestal?
- 1 a 2
- 2 tot 5
- 5 vijf of meer

Wat doet u naast gewoon varen? (meerdere antwoorden mogelijk)
- Waterskien/wakeboarding
- Inflatable trekken
- Zwemmen vanaf de boot
- Aanleggen en zwemmen vanaf de kant
- Vissen
- Anders, namelijk...

Hebt u wel eens stilgestaan bij het aanwezige gevaar van een draaiende schroef?
Nee
Ja

Zo ja, waardoor?

Bent u geïnteresseerd in een systeem dat uw veiligheid vergroot om zorgeloos te kunnen genieten?
Ja
Nee, waarom niet?

Neemt u maatregelen om gevaarlijke situaties met de schroef te voorkomen? (ook tijdens waterskien en zwemmen)
Nee
Ja, namelijk…

Welke eisen stelt u aan een dergelijk systeem?

Wat zou een dergelijk systeem mogen kosten?
Minder dan 200 euro
200 – 500 euro
500 – 1000 euro
1000 euro of meer

___

Weet u dat er systemen op de markt zijn die de veiligheid verhogen?
Ja, ik heb er een geïnstalleerd
Ja, geen systeem geïnstalleerd
Nee

Zo ja, wat vindt u van deze systemen, wat houdt u tegen deze aan te schaffen?

Inleiding vraag
Mogelijke oplossingen van dit veiligheidsprobleem kunnen veranderingen aan uw boot vereisen (installeren van sensoren) of vereisen dat u iets bij u moet dragen (een pols/enkel bandje of iets aan je zwemvest).

Wat geniet uw voorkeur?
Liever geen veranderingen aan mijn boot maar bv. een polsbandje dragen/iets aan zwemvest.
Liever geen polsbandje dragen/iets aan zwemvest maar veranderingen aan mijn boot.

___

Heeft u verder nog opmerkingen tips voor de verbetering van de veiligheid?

Zou u het interessant vinden om op de hoogte gehouden te worden (via E-mail) en/of misschien meer medewerking te verlenen?

Nee

Ja, vul gegevens in

Naam

E-mail

Dank

Hartelijk dank voor uw tijd en moeite! De informatie zal anoniem en vertrouwelijk worden behandeld en zal uitsluitend voor dit project worden gebruikt.

URL:
http://www.studentenonderzoek.com/webform/index.php?formID=1072

8.3 List of Requirements Origin and Explanation

1. Stand alone or build in. A stand alone system has some important advantages. First of all a stand alone system allows the system to be installed on every boat, also already existing boats. I like to give people a choice to protect themselves against the danger of exposed propellers. A second issue is the unwillingness of boat and engine manufacturers. As my expert Gary Polson states: "If your "intelligent system" is integral to a marine drive, it would need to be "built into" the drive and drive manufacturers still refuse to look at anything like that be cause:
   1. If they start using a device like that it may indicate to the courts that their previous units were unsafe.
   2. Even if they do use this device, people will still be hurt now and then and they will then be sued because people will claim the device did not work. So there is a legal stumbling block to the drive companies "buying in". I don't think you will be successful in getting any of them to partner with you."

2. At high speeds the boat's hull and the lower unit of the drive can cause severe damage. (source research: RBBI)

3. A sensor system should not be affected by environmental conditions and give false signals due to waves, prop exhaust, electric ignition circuit of the engine, electric bow-propellers of (other) boats, fish, drive noise, boat noises, noise from people on the boat, fixed objects (piers, docks, dock bumpers) that may be present at takeoff. (source research: RBBI)

4. It should protect persons under all circumstances e.g. not moving, wearing wet suits. (possible technology related exclusions)

5. The system should not raise the impression of a full safety system that excludes accidents from happening and in that way lead to carelessness by the user, causing more danger. People should stay alert and the system should only be additional safety alarming or intervening in case of human failure.

6. The system should be easy of use, not requiring constant attention of the user. It should run in the background providing this much information that the user feels safe. (source user interview)

7. The system should be easy to install on every boat, possibly by the user itself. It should allow the user to install it in a way it suits him/her. (source user interview)

8. The system should be universal and maybe allow exchange between boats, in case people have multiple boats or they like to install it on their new boat. (source user interview)

9. The installation should not require dramatic changes to the boat or drive since some drive manufacturers might void warranty when adaptations are made without the authorizing. It should be removable without leaving holes e.g. (source user interview and US coastguard)

10. The system should be reliable, alarming and intervening only when necessary and always if necessary, not fail at critical moments. (source user interview)

11. The system should not restrict performance e.g. sensors causing additional drag.

12. The system should be subtle, not as eye-catching as most propeller casings, but allow bending in, in the interior. (source user interview)

13. Detect presence of humans at a sufficient distance so the system can react in time. Meaning a quick response time and leaving enough time to make the propeller slow down. (technical criteria)

14. The system should run on a boats power supply of 12 Volts. (technical criteria)

15. Should automatically switch on and of with the engine (to prevent from exhausting the battery when drive is turned of). (technical criteria)

16. Durable and packaged for weather influences and (salt) water environment. (material criteria due to environmental circumstances)

17. Sensors not affected by algae, barnacles and other marine growth. (material criteria due to environmental circumstances)

18. Means of testing the system before take of (like smoke detector push button or automatically at start-up). (technical criteria)

19. Provides feedback that the protection mode is on and when the system inter venes. (user criteria)

20. Good costs/value rate, system should be worth its costs (source user interview)

8.4 Existing solutions

8.4.1 Existing products

RingProp - RingProp PLC [4]

Special shaped propeller which protects humans and marine life against blade cuts.

Pro:
- doesn't decrease the boat's performance
- There are no open propeller blades to catch water-ski lines
- doesn't need adjustments to boat, just replace propeller

Against:
- only protects against side entry
- can entrap limbs and cause more severe injuries
- doesn't protect front and back entry into the propeller

Propeller Guards – several manufacturers (MariTech Industries) [5]

360 degree cover of the propeller.

Pro:
- the surest form of protection available

Against:
- dramatically decrease the boats performance and manoeuvrability
- only applicable for slow boats
- increased area of impact
- they are more easy fouled

"Propeller guards or shrouds have been proposed for use on boats that move at displacement (normally below 20 mph) speeds. At higher planning speeds, the current generation of propeller guards reduce propulsive efficiency and fuel economy, adversely impact boat handling quality, and substitute blunt force trauma for cutting and gouging trauma. Outboard motor manufacturers provide propeller guards as options for slow speed applications but are concerned about resale that results in a high speed misuse." [8]

VirtualLifeline - MariTech Industries [5]

Virtual lifeline, wireless lanyard system which registers if the skipper and/or passengers are ejected into the water and stops the boat.

Pro:
- good protection for falls overboard
- wireless and well wearable
- doesn't need dramatic changes to the boat

Against:
- only protects against falls overboard

The Prop Stopper – MariTech Industries [5]

System that shuts down the engine when the swim ladder is deployed

Pro:
- good protection for swimmers and water-skiers (using the ladder)
- doesn't need dramatic changes to the boat

Against:
- protects only when swimmers use the ladder
- quite expensive

Hydro-Foil Propeller Guard – Cal-Neva Marine [6]

Ring type propeller guard with hydrofoil

Pro:
- easy to install
- increases boat's manoeuvrability
- protects from blade cuts

Against:
- bad protection
- can entrap limbs
- increased area of impact
- they are more easy fouled

PropGuard - W. C. Schultz Engineering INC. [7]

Ring type propeller guard which increases boat performance.

Pro:
- easy to install
- increases boat's manoeuvrability
- increases boat's efficiency
- protects from blade cuts (front and side entry)

Against:
- no full protection
- can entrap limbs
- increased area of impact
- they are more easy fouled

8.4.2 Patents

Also some work has been done on electronic sensorial systems which shut down the engine when an object is detected. Some interesting patents:

US 6,676,460
Multi sensorial system (ultrasonic, infrared) which detects nearby obstacles like see mammals and humans and shuts down electric or combustion engines.

US 6,450,845
Systems that senses the skipper's occupation and intervenes when the skipper is missing.

US 6,416,371
A propeller deflector system which contains inclined vanes mounted to the hull which extends below and beyond the propeller to deflect obstacles. The system is also equipped with sensing technologies which should save human and marine life.

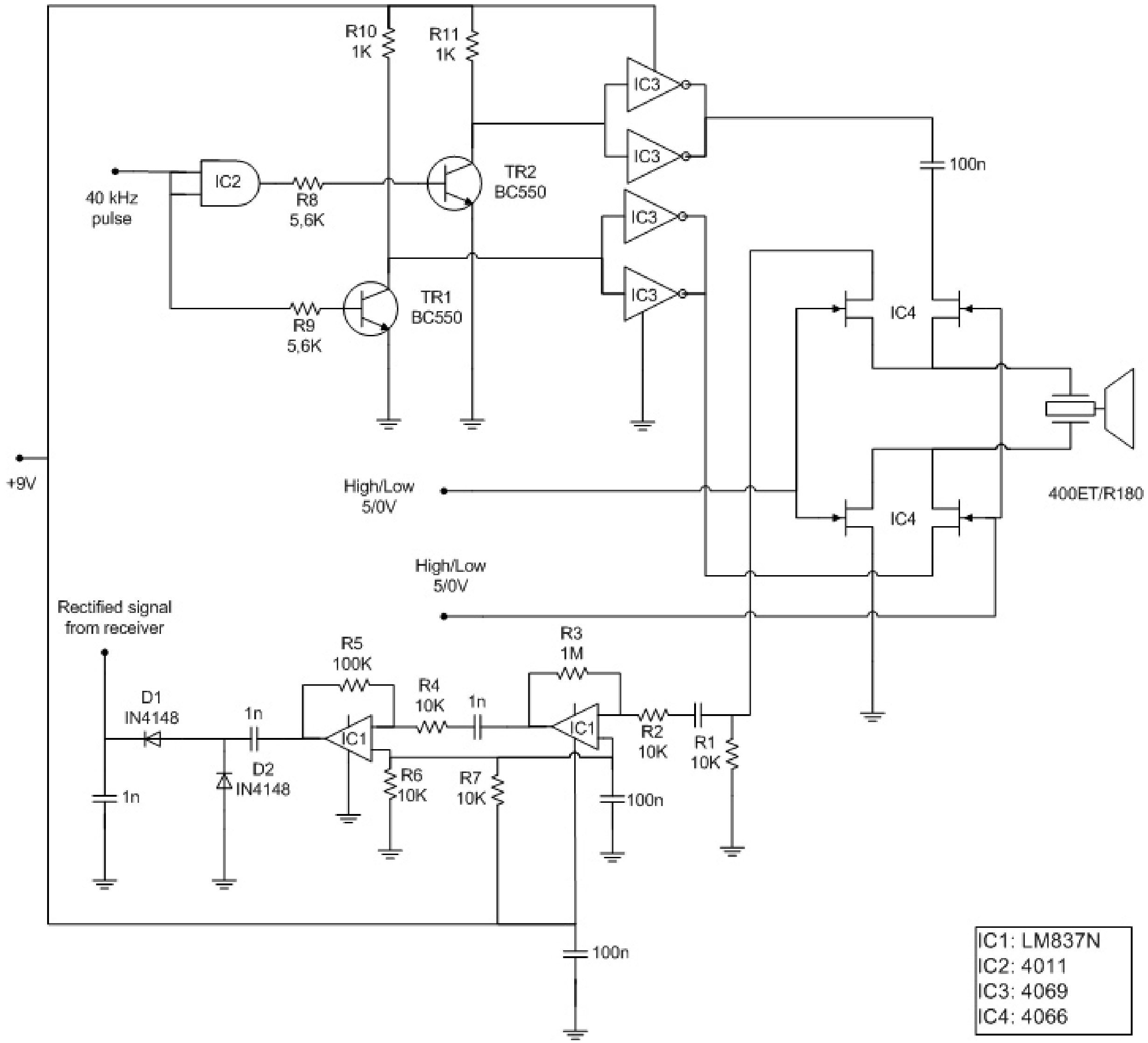
US 6,276,974
Switch to kill the engine for swim ladder door to swim deck, etc.

US 6,273,771
A Boat control system which monitors various conditions like speed, heading, obstacles in the water and human in the area of the boat. The system is capable of taking actions to prevent propeller related injuries.

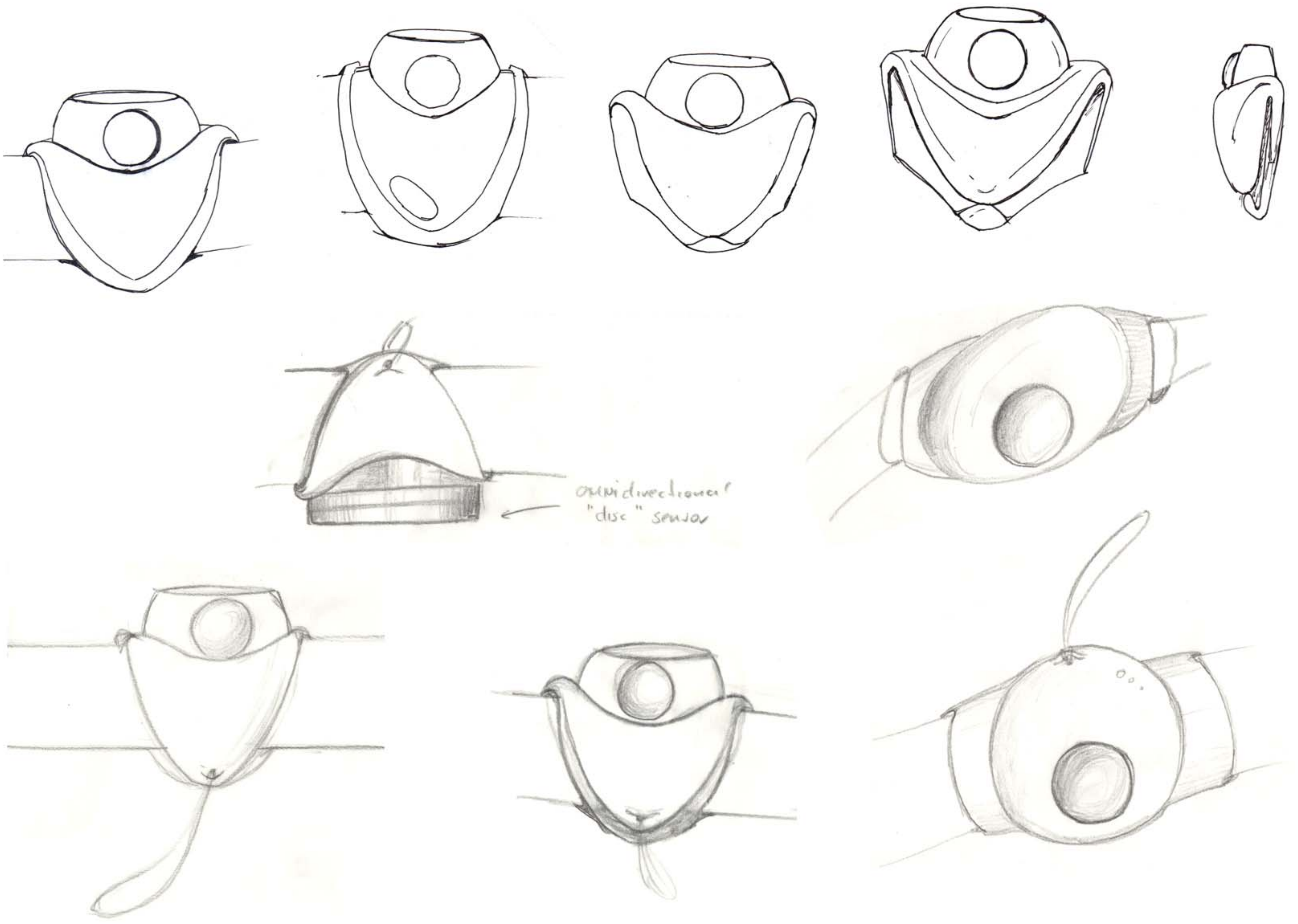
Terminology 8.5

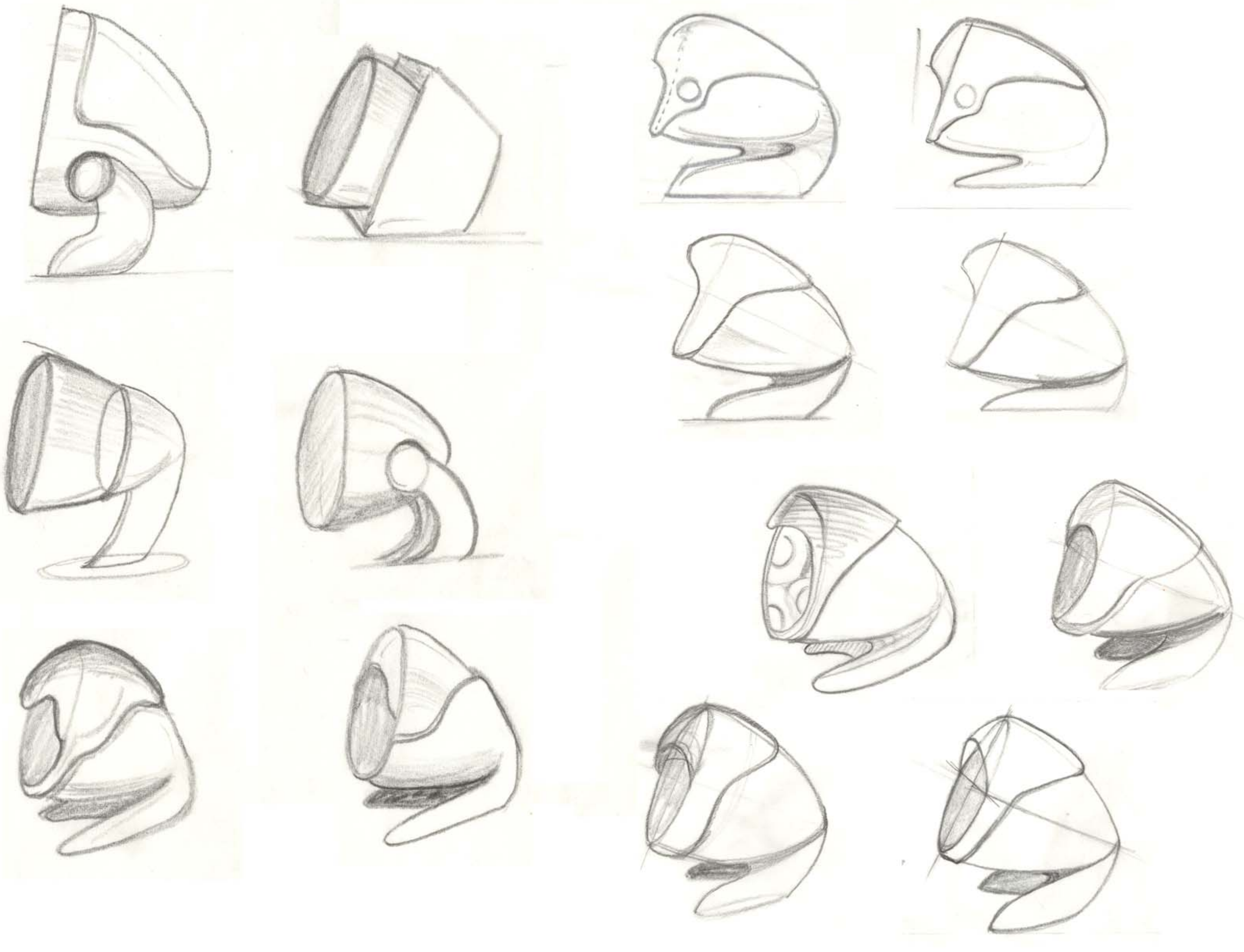
Fast motor boat:	Mechanical propelled boat which can travel at a speed above 20 km/h.
Stern drive:	Propulsion unit, located directly behind the boat which is also used for steering, propelled by an inboard engine.
Inboard engine:	Motor integrated in the boat
Outboard engine:	External engine attached to the rear of the boat, the entire engine turns for steering.
Lanyard ignition Cut-off switch:	Switch attached to a cord to be worn by the skipper; if the skipper falls overboard the cord is detached from the switch and interrupts the ignition circuit.
Planning speed:	The speed whereat the boat's hull does no longer cut trough the water but raises above the water.

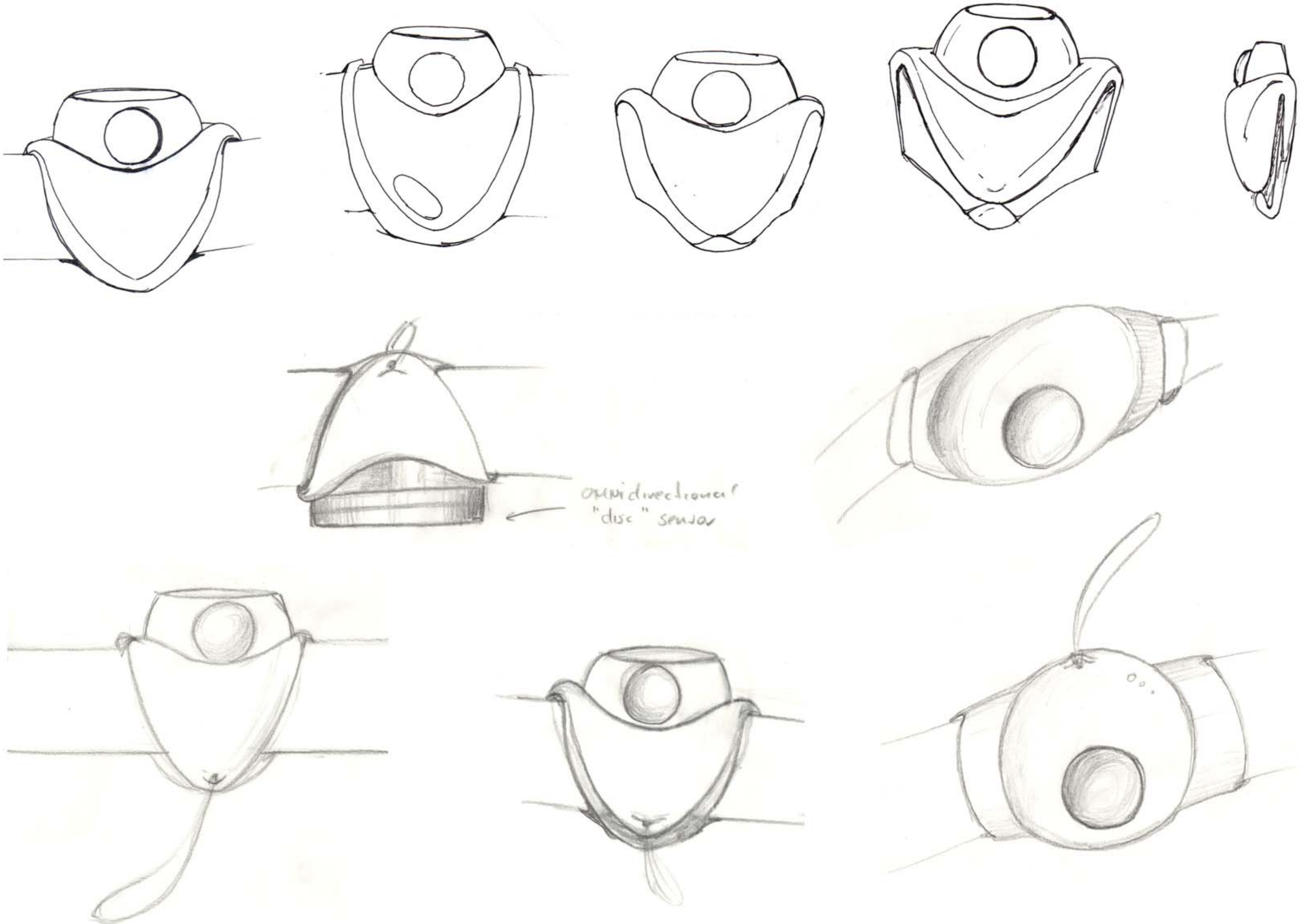
8.6 Circuit Drawing



Design Sketches 8.7


omnidirectional
"disc" sensor




omnidirectional
"disc" sensor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